THE DYNAMICS OF 'SYSTEMS BUILDING':
AN ANALYSIS OF PROCESS MUTATIONS

by

RATHINDRA JURG PAUL

Bachelor of Architecture (Honours)
Indian Institute of Technology,
Kharagpur, India
June 1975

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN
ARCHITECTURE STUDIES

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1984

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Signature of Author

Rathindra Jurg Paul
Department of Architecture
May 11, 1984

Certified by

Eric Dluhosch
Associate Professor of Building Technology
Thesis Supervisor

Accepted by

N. John Habraken, Chairman
Department Committee on Graduate Students

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RATHINDRA JURG PAUL

Submitted to the Department of Architecture on May 11, 1984
in partial fulfillment of the requirements for the degree
of Master of Science in Architecture Studies.

ABSTRACT

This thesis investigates systems building in architecture.
As the systems approach is an organized process for
problem solving, the understanding of structural and
functional relationships is essential.
As systems building can be interpreted in terms of
dynamic processes, that are transient and at times
teleological in nature, an attempt is made to uncover and
define the invariant and contingent factors.
As a systems performance is determined by methods of
prediction and specification, preferred techniques and
directions are explored.
As an analysis of process mutations can lead to insights
into the creation of systems and their functioning, methods
of evaluation are proposed that may make systems building
more effective.
As knowledge bases are often scarce or inappropriate for
systematic applications, a framework for systemic support is
outlined.
This thesis does not propose anything new, instead it
concentrates on uncovering the new in the old.

Thesis Supervisor: Dr. Eric Dluhosch
Title: Associate Professor of Building Technology.
ACKNOWLEDGEMENTS

TO THE FEW I RESPECT
TO STOLEN IDEAS
TO LONELY PARENTS
TO MY ADVISOR
THANKS

RATHINDRA JURG PAUL
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INTRODUCTION

This thesis investigates systems building in architecture. It does this in four sections:

The first presents a series of concepts in systems theory and on the growth of knowledge. The dual functional-structural organization of systems is investigated and these ideas are later applied to Systems Building and methodological problems in design.

Many parallels between theory and approach that have been identified, are translated and elaborated in the second section. The main emphasis being on systems dynamics and the performance approach. The intention is to show how dynamic concepts are related to the total building process, at various hierarchical levels within the system.

The third section is an analysis of process mutations in their various manifestations and occurrences in all sectors of the construction industry. An abstract procedure for assessing such evolutionary or revolutionary changes is developed. Such formulations help in problem definition and solving.

Besides envisaging a change in scope and emphasis of systems building in architecture, the thesis also attempts to formulate a strategy for providing adequate support. This section briefly outlines such a framework based on productions and expert knowledge.

Mutations in building systems development can be traced through specific domains. The appendix covers some such aspects of Systems Building in Educational Facilities.
ON SYSTEMS

1.0 INTRODUCTION
1.1 CREATIVITY AND THE GROWTH OF KNOWLEDGE
1.2 SYSTEMS THINKING
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1.7 METHODOLOGICAL PROBLEMS
1.8 CONCLUSION
1.0 INTRODUCTION: SYSTEMS

There are many a thoughts on the act of creation. But only when volitional can one discern a method to it. Creation implies change, and the initiation of change is through design. Abstractions are the conceptual tools of understanding. Models are integrated abstractions, which in their turn form systems of thought that lead to design.

How are such systems of thought built? And when externalized how do built systems function? The methods used are twofold, either one studies the act of creation as it is evolving from a priori or descriptive mode, or one looks at it from a posterior or prescriptive mode. But whichever approach one takes, the idea is to enhance descriptive and ought-to-be states.
1.1 CREATIVITY AND THE GROWTH OF KNOWLEDGE

The central problem of epistemology has always been and still is the problem of the growth of knowledge. As scientific knowledge can be viewed as an extension of common sense knowledge, it is still the preferred approach to the problem.

Ideas for modelling design in the past have mostly been methodologies of the natural sciences, with the attendant mechanistic views of cognitive psychology, information theory, and operations research. Recent philosophies of science show more promise, because there is a recognition that scientific methods are not absolute, and that considerable diversity exists within coherent scientific activity.

A MODEL OF DESIGN

The only significant model of design in general, developed in the early 1960's, explains the process of design as a sequence of analysis, synthesis and evaluation.

'Analysis' is the investigation of the problem, the finding and the articulation of requirements to be fulfilled, and the assembly of data.

'Synthesis' is the taking of requirements and data and the inventing of a design.

'Evaluation is the checking of the design against the requirements and providing feedback for future design.

It was soon discovered that this apparently linear process was in fact cyclical, with phases of progress and rethinking. The model also seemed to focus more on the productive process than on the process of design.

Analysis at first seems to fit the accent on innovative design, where the approach is to start from scratch, and explore all areas of possibility in search for an optimum solution to a problem. This is opposed to more conventional design, in which the designers' experience of methods and solutions form important precedents for future designs. An information processing model of design must therefore also
include inputs such as designers skills, experiences, 
preconceptions, values, etc.

Further, analysis is not entirely geared to innovation, 
since it has to begin with requirements that can rarely be 
treated in an abstract context free manner. So a model of 
design must include the possibility of varying degrees of 
conventionalism and innovation.

Ignoring the designer is also noticeable in the modelling 
of synthesis. Either synthesis is said to be mysterious (a 
black box), or it is viewed as a mechanical process (in a 
glass box). Both views are plausible explanations, as they 
depend on the perceiving levels of the observer. If the 
model were to match different perspectives, part of it would 
remain mysterious to each one, but would be explicit 
collectively.

There is a hint of perfection in the model of evaluation 
as a phase of matching the design against the requirements. 
Such a view can create problems where requirements are ill 
defined. It also leaves no room for fulfilling requirements 
that weren't articulated, or for innovation in general.

THE NATURAL SCIENCES

As the natural sciences have long provided a model for 
research in other fields, it seems plausible to extend this 
analogy to design as well. One way of interpreting the 
philosophy of science is to view it as a competition between 
different ideas of scientific reasoning.

In the 'inductive' method of reasoning a conclusion (law 
of nature) is drawn from evidence already known. It is the 
act or process of devising general principles from 
particular facts or instances. In the 'hypothetico 
deductive' method of reasoning, a law which has been 
preconceived is tested by drawing conclusions from the law 
and testing them by further observations. It is inference by 
reasoning from the general to the specific.

The inductivists argument rests on three general 
principles:
1. The principle of accumulation (analysis),
2. The principle of induction (synthesis), and
3. The principle of instance confirmation (evaluation).

Critics claim that none of these principles will hold. First, history shows the growth of science to be a leapfrog process of fact accumulation and theoretical advances. As knowledge is not independent of theory, new theories can refute old facts. Secondly, even if the simplest laws are selected from the infinite number that can be induced, history has shown that the laws of nature are always more complex than originally conceived. Finally, the principle of instance confirmation assumes that patterns of phenomena do repeat themselves, but such evidence is circumstantial. Hence inductive reasoning is tautological in that its reasoning depends on assuming the correctness of the method itself.

CONJECTURES AND REFUTATIONS

As an advocate of the hypothetico-deductive school of thought, Popper (1963) is best known for his doctrine that knowledge grows by a process of 'conjectures' and 'refutations'. Conjectures, for Popper are 'tentative' solutions to problems, which have no logical basis in existing facts. Rational processes enter the picture only after the hypothesis has been formed.

Further, Popper (1968) argues that since the discovery of any one deviation is enough to disprove a theory, the mathematical probability of any theory is zero. Hence scientific theories are neither based on, or established on facts, but only 'refuted' by them.

The demarcation criteria used to distinguish between real theories and pseudo-theories are:
1. A theory is only useful if its predictions are in conflict with common sense, and confirmations are only useful if they confirm such 'risky' predictions or bold conjectures.
2. Bad theories explain a great many things, but a good
scientific theory actually forbids things. The more things it forbids the better.
3. Theories must not be so general, as to be quite irrefutable. Scientific theories must contain 'potential falsifiers'.
4. There is no point in trying to confirm a theory, for one can always ignore contrary evidence. The only genuine test is an attempt to falsify it, or refute it.
5. Any attempt to refute a theory which actually confirms it can be taken as 'corroborative evidence'.
6. If in the light of some refutation a theory is reinterpreted, then if the interpretation does not actually destroy the theory, it certainly lowers its scientific status.

This represents an all important shift in the problem of the normative philosophy of science. Instead of providing a book of rules for arriving at a hypothesis, the logic of discovery consists merely of a set of rules for the appraisal of already existing theories. All the rest is seen as a matter of psychological study of creativity, outside the normative realms of the logic of discovery.

If metaphor is taken as fundamental to creative thinking (conjecture), we can see that the choice of metaphor and the degree of transformation can model the degree to which a design is conventional or innovative. Thus one would not require two types of creativity, the conventional and the innovative.

PARADIGNS, PUZZLE SOLVING AND CRISIS

One of the limitations of learning from Popper is that he focuses on individual theories, whereas knowledge and skill is shared by communities of designers.

Kuhn (1962) observed that the idea of bold conjecture and austere refutations did not occur in practice. Refuted theories were tenaciously maintained in the face of apparent counter-examples, and existing theories that appeared to better on hindsight were often ignored or held at bay. This
is not the behavior of individuals, but of a community, which has developed a fundamental pattern of ideas on a subject. This Kuhn called a 'paradigm'.

Scientific communities he claims in general do 'normal science', i.e. making adjustments and refinements to details, to thesis that support the paradigm. Thus normal science is a process of 'puzzle solving', the answers to which are already given in principle by the paradigm.

When there are difficulties in puzzle solving, and an individual produces results that are in conflict with the paradigm, the results are ignored or put aside for later attention. But the weight of difficulties may eventually bring the paradigm itself under question. This creates a 'crisis' and a shift or switch of paradigm by some or all of the scientific community.

Parallels with design are also evident. However the inexact science of design doesn't easily allow a paradigm switch, for it would need a plausible alternative. In general only paradigm shifts are accommodated. Paradigm shifts can be interpreted as dynamic evolutionary changes, whereas paradigm switches are revolutionary or more fundamental mutations.

Design can also be seen as a mix between conventional problem (normal puzzle) solving, and more innovative design, the result of a crisis, or a fundamental departure from the conventional.

NO RULES, COUNTER-INDUCTION

Anarchist, Feyerabend (1975) sees science as radically changing. For him, scientific rationality is a myth, there never was such a thing as an 'objective science'. "Science has always been much more 'sloppy' and 'irrational' than its methodological image." He argues that such a view is not only substantiated by history, but is also a 'precondition for progress'.

Feyerabend not only opposes such theories as inductivism and falsification, but is against any attempt to lay down
universal rules for the conduct of science. He argues that since we cannot conclusively disprove a theory there are no absolute views. Further, if we look at significant paradigm shifts; the innovations in science, we can see the need to ignore or go against consensus.

Feyerabend’s advise is to proceed ‘counter-inductively’, to introduce and elaborate hypotheses which are inconsistent with well established theories and/or facts. That change requires some rejection of the past is a useful emphasis, and his account of how this happens should be applicable to design modelling.

He also raises the question of what science is for. His view is that it is for the enlightenment and self-fulfillment of man (the scientist) and hence mankind. This is in contrast to the rationalists Popper and Lakatos who see scientist’s aim at the growth of knowledge. Feyerabend at least raises the issue of whether individual motive should be quite so noble and selfless.

RESEARCH PROGRAMS AND PROBLEM SHIFTS

Opposed to Feyerabend is Lakatos (1970, 1978), who has attempted to rehabilitate Popper, by indicating that he was concerned with a series of theories, not individual ones, so that he was not actually writing about refuting one theory, but on continuously improving it.

Lakatos fits this into his own view of science, which has as its core a ‘research program’ similar to Kuhn’s paradigm. However the dicotomy of normal science with its puzzles and crises is replaced by the idea of progressive and degenerative ’problem shifts’. The scientific community which supports and works on a particular program of research has various rules for defending the core of the program (the negative heuristics) and rules for directions to explore (the positive heuristics). These rules are not necessarily explicit. When things go well, there is a progressive problem shift, i.e. the core ideas are developed. There are negative shifts when counter-examples and other problems can
lead to fundamental questioning of the core ideas of the research program. But this does not necessarily lead to the abandonment of the program.

The idea of a balance between positive and negative, between growth and setback and the potential for discussing fundamentals at any time, seems more realistic than Kuhu's view that such discussion is only part of a crisis. We may be able, to fairly directly model for design the equivalent for positive and negative heuristics, explicit and implicit rules for design action.
1.2 SYSTEMS THINKING

REVOLUTION AND CHANGE

Satisfaction/satisficing are the perceptual/conceptual parameters/measures of existence. The degree of freedom/independence or the lack of it are the delimiting criteria. As modern man's need to dominate or escape from his environment are curtailed, he initiates revolutions. One could say that they reflect some very basic 'cultural' changes, which interrelate changes in man, his environment, and how and what he thinks about it.

Alvin Toffler (9171) states that, "As interdependency grows, smaller and smaller groups within society achieve greater and greater power for disruption. However, as the rate of change speeds up, the length of time in which they can be ignored shrinks to near nothingness." Hence the relations that accompany change require new assertions of control and being.

Any revolutionary change will thus either generate a crisis or be bypassed/ignored and hence silently assimilated. In either case such changes give rise to new interpretations of what is happening and also new ideas as to what can be done about it. Changes that don't go into effect and hence lie dormant, or as yet unthought of changes, form another spectrum of potential ideas, that may yet become revolutionary.

It is this change that Ackoff (1974) identifies, "We are going through an intellectual revolution that is as fundamental as that which occurred in the Renaissance. The Renaissance ushered in the Machine Age which produced the Industrial Revolution. The currently emerging intellectual revolution is bringing with it a new era that can be called the 'Systems Age' which is producing the 'Postindustrial Revolution'." Machine Age thinking was 'analytical', whereas Systems Age thinking is 'synthetic'.

ANALYTIC THINKING: REDUCTIONISM AND MECHANISM
Analytical thinking of the Machine Age was based on the doctrine of 'reductionism' and 'mechanism'. Reductionism is a doctrine that maintains that all objects and events, their properties, and our experience and knowledge of them are made up of ultimate indivisible elements. It is the mental process by which anything to be explained, hence understood, is broken down into parts. Explanations of the behavior and properties of wholes were extracted from explanations of the behavior and properties of the parts.

Analysis was also central to problem solving. Problems to be solved were first reduced by analysis to a set of simpler problems, the partial solutions of which were assembled into solutions of the whole.

When the whole to be explained could not be disassembled into independent parts, the relation between them had to understood to understand the whole. Consistent with reductionism it was believed that all interactions between objects, events, and their properties could be reduced by an analysis to one fundamental relationship, "cause-effect". One thing was said to be the cause of another, its effect, if the first was both "necessary" and "sufficient" for the other.

Because a cause was taken to be sufficient for its effect nothing was required to explain the effect other than the cause. consequently, the quest for cause was "environment free." It employed what is now called "closed-system" thinking.

Deterministic causal thinking lead to the belief that every phenomena was explainable in principle by the laws that governed matter and motion. Such a view was called 'mechanism'.

Those that held mechanistic views found no need for teleological concepts; function, goal, purpose, choice, and free will, in explaining natural phenomena. The universe came to be regarded as a machine, with the first cause and ultimate purpose as God.

The replacement of man by machine as a source of
physical work, effected the nature of the task left for man to perform; those that could not be mechanized. Men and machines were organized into processing networks the result of which is the mass production and assembly line. Men no longer did all the things required to make a product, but repeatedly performed simple operations that were a small part of the production process. Consequently, the more machines were used as a substitute for men, the more men were made to behave like machines. It is not surprising that a society that thought the world as a machine came to think of man as one also.

SYNTHETIC THINKING: EXPANSIONISM AND TELEOLOGY

The new intellectual framework of the Systems Age did not destroy or discard the one it replaced, but instead supplimented and partly replaced it by the doctrine of 'expansionism' and 'teleology', and a new 'synthetic' or 'systems' mode of thought.

Expansionism is a doctrine that maintains that all objects, events, and experiences of them are part of larger wholes. It turns attention from ultimate elements to 'wholes with interrelated parts', to systems. Expansionism is thus different from, but compatible with reductionism.

In 1942 Suzanne Langer argued that philosophy had shifted its attention from elementry particles, events and their properties to a different kind of element, the 'symbol'. A symbol is an element that produces a response to something other than itself. Its physical properties are of no essential importance. later, Morris extended this concept into a frame work for the scientific study of symbols and the wholes, language of which they were a part. This was followed by the growing importance given to semiotic, the science of signs and symbols, and to linguistics, the science of language. It was natural for many to maintain that what we know about reality is reflected in the signs with which we represent its content and in the language of which these signs are a part. But some (Whorf 1956) went
further and claimed that what we know of reality is conditioned by the language we use; hence the nature of reality is to be found in the analysis of language.

With the work of Shannon (1949) attention turned to a larger process of which language was a part, communication. Almost simultaneously Wiener (1948), placed communication into a still larger conceptual context, control. This progress from Symbol through language, communication, and control was one from elements to wholes. It was expansonistic, not reductionist.

In the early 1950's science went through an "aha" experience and came to realize what it had been upto in the preceding decade. It was becoming preoccupied with "systems". Attention was drawn to this concept by biologist von Bertalanffy (1968) who predicted that it would become a fulcrum in modern scientific thought. He saw this concept as a wedge which would open science's reductionist and mechanistic views of the world so that it could deal more effectively with problems of living nature; with biology, behavioral, and social phenomena, for which he believed application of physical science was not sufficient, and in some cases not even possible.

THE INTERDEPENDENCE OF DISCIPLINES

One important consequence of this type of thinking is that science itself has come to be reconceptualized as a system whose parts, the disciplines, are interdependent and applicable to the study of most phenomena and problems. In the Systems Age science is developing by assembling its parts into an expanding variety of increasingly comprehensive wholes. The relatively new developments, such as cybernetics; operations research; the behavioral, communication, management, and policy sciences; and systems engineering, are interdisciplinary, not disciplinary. Even the interdisciplines are seen as part of a still larger whole, the systems sciences which, note, form a system of sciences.
In the past a complex problem was usually decomposed into simpler problems for different disciplines to solve. Partial solutions would then be assembled into a solution of the whole. But contemporary interdisciplines do not work this way; a variety of disciplines work together on the problem as a whole.

Unlike traditional scientific disciplines which seek to distinguish themselves from each other and to spin off new disciplines, the new interdisciplines seek to extend themselves and merge with each other, enlarging the class of phenomena or disciplines with which they are concerned. They strive for more comprehensive synthesis of knowledge and therefore thrive on interaction with each other.

CAUSALITY, OPEN AND CLOSED SYSTEMS, AND TELEOLOGY

At the turn of the century, the philosopher of science, E.A. Singer, noted that causality was used in two different senses. Deterministic, when a cause is both necessary and sufficient for its effect, and probabilistic it is necessary, but 'not' sufficient for the effect. Singer referred to the second type of cause-effect as 'producer-product'.

As a producer is not sufficient for its product, other coproducers are necessary. Taken collectively these constitute the producer's environment. Hence, the producer product relationship yields environment-full (open-system), not environment-free (closed system), thinking.

Cybernetics, showed the great value of conceptualizing self-controlling machines as functioning, goal-seeking and purposeful entities. In the past man had been studied as though he were a machine, now it was becoming at least as fruitful to study self-controlling machines as if they were men. Thus, in the 1950's, 'teleology'; the study of goal-seeking and purposeful behavior, was brought into science and began to dominate over concepts of the world.

In mechanistic thinking behavior is explained by identifying what caused it, never by its effect. In
teleological thinking behavior can be explained either by
(i) what produces it, (ii) by what it produces, or (iii) is
intended to produce.

AUTOMATION AND INTELLIGENT CONTROL

The Systems age is based on three technologies:
1. Devices that mechanized communication, the transmission
   of symbols. As symbols are not made of matter, their
   movement through space does not constitute physical work. 2.
   Devices that can observe and record the properties of
   objects and events. Such machines generate and remember
   symbols that are called 'data'. Instruments can observe what
   humans cannot without mechanical aids, and such observation,
   like communication, is not physical work.
3. The key technology appeared with the development of the
   electronic digital computer. The logical manipulation of
   symbols permits processing of raw data into usable form;
   information, and its convert into instruction. Thus it is
   both a data-processing an instruction-producing machine.

These technology make it possible to mechanize mental
work, to automate. Automation is what the Systems Age is all
about.

Development and utilization of automation technology
requires an understanding of the mental processes involved
The many interdisciplines that have developed to generate
and apply understanding of these mental processes and their
role in control, provide the "software" of the Systems Age
just as industrial engineering provided much of it
previously. The key to the future is intelligent control.

THE ORGANIZATION & CONTROL PROBLEM OF THE SYSTEMS AGE

Because the Systems Age is teleologically oriented it is
preoccupied with systems that are purposeful; that is,
display choice of both means and ends. What interest remains
in purely mechanical systems derives from their use as tools
by purposeful systems. Furthermore man is most concerned
with those purposeful systems whose parts are also
purposeful, with 'groups', and with those groups whose parts perform different functions, 'organizations'.

All groups and organizations are parts of larger purposeful systems. Hence all of them are purposeful systems whose parts are purposeful systems and which themselves are part of a larger purposeful system.

Therefore, there are three central problems that arise in the management and control of purposeful systems: how to increase the effectiveness with which they control their own purpose, the purpose of their parts, and the purpose of the system of which they are part. These are, respectively: (i) The self-control problem of designing and managing systems that can cope with complex sets of interacting problems in dynamic environments. (ii) The humanization problem of serving the purpose of the parts of a system more effectively so as to better serve the purpose of the system itself. (iii) The environmentalization problems of serving the purpose of environmental systems more effectively so as to better serve the purpose of the system.
1.3 GENERAL SYSTEMS THEORY

Both extrinsic and intrinsic reasons support the need for a synthetic and well informed philosophy.

EXTRINSIC REASONS

Analysis demands specialization and the corresponding splitting of the philosophical camp into specialists of its various branches. But the world is much more like a system or network in which the knowledge of one element presupposes familiarity with all others. And even if this presupposition diminishes in import beyond specified limits, the effects of interventions based on limited knowledge transcends it and embraces much wider boundaries. This is true of science as well as philosophy.

Synthesis in the field of knowledge has yet another crucial task to fulfill. It has to help us to overcome what has been described as the "existential vacuum." As the synthetic faith and imagination of earlier epochs have lost their cogency, the demand for seeing things whole and interconnected is felt more urgently. One can agree with Maslow (1951) that, between the two modes of thinking, the "atomistic" and the "holistic", it is the holistic which is the sign of the healthy self-actualizing person. Nihilism on the other hand is closely linked to reductionism.

INTRINSIC REASONS

Coherent and systematic theories of the empirical world are based on two "primary presumptions": (a) The world exists; and (b) The world is, at least in some respects, intelligently ordered (open to rational enquiry).

The secondary suppositions are: (a) The world is intelligibly ordered in special domains; or (a) The world is intelligibly ordered as a whole.

One or the other presuppositions is made by every investigator. The specialist normally refuse to admit such presuppositions, usually considered them to be in need of demonstration. He dosen't question the intelligibility of
his domain, nor its links with other than neighbouring ones. The generalist makes precisely the contrary assumption, that knowledge of events in any one domain becomes fully intelligible only when brought into conjunction with the knowledge of events in other domains.

If theories rest on prior presuppositions then neither special nor general theories have a privileged status. However, if the world is intelligibly ordered as a whole, then the more regions of order disclosed by a theory, the more that theory is divested of the personal bias of the investigator.

PERSPECTIVISM

Laszlo (1972) states, "Systems philosophy reintegrates the concept of enduring universals in transient processes within a non bifurcated, hierarchically differentiated realm of invariant 'systems', as the ultimate actualities of self-structuring nature. Its data comes from the empirical sciences; its problems from the history of philosophy; and its concepts from modern systems research".

General systems theory grasps some form of order in this world which eludes other type of theories. And since it provides the greatest range of invariances ("laws") it is best suited to grasp a general order recurring in logically differentiated transformations.

A general order is, in all intrinsic respects, as good a presupposition as any special order, and in extrinsic respects, it is a considerably better one.

CREATIVE DEDUCTION AND IN Variant STRUCTURING

"Creative deduction" is a method which forms a common bond between contemporary science and general systems theory. The presupposition of general 'orderability' (if not necessarily 'order') in nature expresses itself in the isomorphism of the laws and principles formulated in regard to systems of different kinds. This structural uniformity was first pointed out by von Bertalanffy (19..).
Such creatively postulated and deductively applied systems constructs include wholeness, feedback, steady and stationary states, entropy, and many others. In virtue of the inclusive applicability of such constructs, much of the universe available to our scrutiny can be conceptually "mapped" as hierarchies, i.e., as a realm of systems-in-environments, constituting higher order systems which, within their particular environments, constitute systems of still more inclusive order.

SECOND ORDER MODELS
Systems constructs are possibly the best contemporary instruments for building models of other (empirical) models. If we assume that reality is merely mapped by the models and not determined by them, it follows that the models give so many perspectives of what may be a common underlying core of events. General systems theory's task is to uncover that core.

A mere analysis of the models yields an undoubtedly clarified but still one-sided and uncoordinated view of the world; thus analysis must be supplemented by synthesis. Synthesis can follow essentially the same procedure as model-building in the empirical sciences, taking place however on a "second-order" meta-level.

The data of systems synthesis are theories; "first-order" models of the experienced world, and not experienced themselves.

RELATIONAL ENTITIES AND INTERFACES
In the new physics, the general constructs of ordered wholes are not represented by exact laws, but by continuous "fields". Field strengths can only be represented probabilistically, as elements are considered to 'exist simultaneously' in every part of the space. Consequently, systems are viewed as complex dynamic patterns formed by the sharing of boundary elements. Boundaries or 'interfaces', have characteristic informations, energies, substances, etc.
Ordered totalities constitute, at the basic physical level, fields, and on higher levels, systems within the fields, and systems within systems within fields; and so on, in a complex hierarchy of organization.

Organized functional systems, relate to one another by "horizontal" interactions within their own level as well as by "vertical" interactions between different levels.

The units of diverse special sciences are now largely reconceptualized as dynamic systems, that are unclearly interrelated. What is require, is their integration into a second-order general model.

NATURAL SYSTEMS AND HEAPS

A "natural system" is a "nonrandom accumulation of matter-energy, in a region of physical space-time, which is non randomly organized into coacting interrelated subsystems or components." The exception being "primary" or "least hierarchical" systems. Such regularities add up to conceptually discoverable invariances, i.e. differential equations stating functional relations between variables.

The definition excludes all "aggregates" or "heaps" of natural events, i.e., matter-energy agglomerations which do not interact or coact, although sharing a defined space-time region. It is always possible that a "heap" should transform into a "natural system" by virtue of components entering into systematic interactive or coactive relationships with each other. Such a phenomena would be one form of evolution.

Each system within the hierarchy is capable of conceptualization as a system manifesting the postulated invariances in the coaction of its parts as well as in its total system coaction with systems in its surroundings.

Mapping invariances by means of creatively postulated general systems constructs overcomes the difficulties entailed by the usual approaches to the investigation of natural systems.

One such approach is to ask, in regard to a system, "how does it work?" Such a task may be reductionist in intent,
though not necessarily in result. Alternately, one may ask "how do the constraints constituting the interrelations of the parts arise?" It is often held (Polanyi 1968) that the laws defining the constraints of the whole are not derivable from the laws of the parts. Such a view is non-reductionist, and can lead to pluralism or dualism depending on the areas of irreducibility.

SYSTEMS AND PERFORMANCE

A system is a set of two or more interrelated elements of any kind; i.e., concepts, objects or people. Therefore, it is 'not' an ultimately indivisible element, but a whole which can be divided into parts. The elements of the set and the set of elements have the following properties:

1. The properties or behavior of each elements of the set has an effect on the properties or behavior of the set taken as a whole.

2. The properties and behavior of each element, and the way they effect the whole, depends on the properties and behavior of at least one other element in the set. Therefore, no part has an independent effect on the whole and each is affected by at least one other part.

3. Every possible subgroup of elements in the set has the first two properties: each has a nonindependent effect on the whole. Therefore the whole cannot be decomposed into independent subsystems.

Because of these three properties, a set of elements that forms a system has some characteristics, or can display some behavior, that none of its parts or subgroups can.

Viewed "structurally", a system is a divisible whole (analytic), but viewed "functionally", it is an 'indivisible whole' (synthetic), in the sense some of its properties are lost when it is taken apart.

The synthetic mode of thought, when applied to systems problems, is called the "systems approach". In this approach a problem is not solved by taking it apart, but by viewing it as a part of a larger problem. This approach is based on
the observation that when each part of a system performs as well as possible relative to the criteria applied to it, the system as a whole seldom performs as well as possible relative to the criteria applied to it. This follows from the fact that the sum of criteria applied to the performance of the parts is seldom equal to the criteria applied to that of the whole.

"Systems performance" depends critically on how well the parts 'fit and work together', not merely on how well each performs when considered independently. Further, a system's performance depends on how it relates to the environment; the larger system of which it is a part, and to other systems in the environment. Therefore, in systems thinking, an attempt is made to evaluate performance of a system as a part of the larger system that contains it.
Fig. 1.3.1
Inverse ratio of quantitative abundance and qualitative diversity.

Fig. 1.3.2
Inverse ratio of overall structural stability and range of self-stabilizing functions.
1.4 THEORY OF NATURAL SYSTEMS

The here presented theory of Ervin Laszlo (1972), is an attempt to map a few systems properties, that are applicable throught the range of phenomena, including man himself, his environment and experience.

THEORY

\[ R = f(a,b,c,d), \text{ where } a,b,c,d \text{ are independent variables having the joint function } R \text{ ("natural system")}. \]

a : Coactive relation of parts resulting in 'ordered wholeness' in the state of the system ("systemic state property");

b : Function of adaptation to environmental disturbances resulting in the 're-establishment' of a previous steady state in the system ("system-cybernetics I");

c : Function of adaptation to environmental disturbances resulting in the 'reorganization' of the system's state, involving, with a high degree of probability, an overall 'gain' in the system's 'negentropy' and 'information content' ("systems cybernetics II");

d : 'dual' functional-structural 'adaptation': with respect to subsystems (adaptation as systemic 'whole') and suprasystems (adaptation as coacting 'part') ("holon property").

THE INDEPENDENT VARIABLES

\[ R = f(a) \text{ (SYSTEMIC STATE PROPERTY)} \]

NATURAL SYSTEMS: WHOLENESS AND ORDER

An 'ordered whole' is a non-summative system in which a number of constant constraints are imposed by fixed forces, yielding a structure with mathematically calculable parameters.

The concept 'wholeness' defines the character of the system as such, in contrast to the character of its parts in isolation. The whole is other than the simple sum of its parts. Traditionally, wholes were often considered to be
quantitative and intrinsically unmeasurable entities because they were seen as "more then the sum of their parts." This concept is spurious.

Wholes are other than the simple sum of the properties and functions of their parts. Complexes of parts can be calculated by: (i) counting the number of parts, (ii) taking into account the species to which the parts belong, and (iii) considering the relations between the parts. The wholes in the first two cases have cumulative characteristics that are better known as "heaps" or "aggregates". The fact that the parts are joined, makes no difference to their function, as in a heap of bricks.

Systems that form ordered wholes are constitutive complexes in which the law-bound regularities exhibited by interdependent elements determine the functional behavior of the totality. Mathematical examples for both "summative" and "constitutive" complexes can be readily found.

DEFINITION OF "SYSTEM-CYBERNETICS"

"Cybernetics" the science of control, though often restricted to the study of flow in closed systems, will be taken in a wider open context, as the study of processes interrelating systems with inputs and outputs.

Two kinds of system-cybernetics can be distinguished; (i) the study of self-stabilizing controls operating by error-reduction negative feedback (Wiener), and (ii) the study of error (or deviation) amplifying control processes, which function by means of positive feedback (Maruyama).

These two forms of system-cybernetics give us a qualitatively neutral conceptual tool for assessing processes which result in the pattern-maintenance, as well as the pattern-evolution, of ordered holistic systems through periodic, or constant, energy or information exchanges with their dynamic environment.
If a system is entirely governed by its fixed forces, the constant constraints these impose bring about an unchanging steady state. If, however together with the fixed forces some unrestrained forces are present in the system, it is capable of modification through the interplay of the forces present in, and acting on it. The presence of some fixed forces is sufficient to bring about a state which persists in time ("steady state") when all the forces in the system which correspond to the unrestrained forces vanish. Fluctuations in the system are resolved due to the fact that the flow caused by the perturbation must have the same sign as the perturbation itself. If the fixed forces are conserved, the stationary state is characterized by their parameters, since the unrestrained forces vanish. If both the fixed and the unrestrained forces are removed, the system is reduced to a state of thermodynamic equilibrium. "Ordered wholes" are always characterized by the presence of fixed forces, excluding the randomness prevailing at the state of thermodynamic equilibrium. Thus ordered wholes, by virtue of their characteristics, are self-stabilizing in, or around, steady states. Given unrestrained forces introducing perturbations which do not exceed their threshold of self-stabilization, they will return to the enduring states prescribed by their constant constraints.

Stable equilibrium in systems, is the capacity of self-regulation by compensating for changing conditions in the environment through coordinated changes in the system's internal variables. Thus, a complex is a system if the varience of the features of the whole collective is significantly less than the sum of variances of its constituents. Inasmuch as systems of this kind reorganize their flows to buffer out or eliminate the perturbations and thereby conserve a relative invariance of their total complex compared with the greater range of variation in their coacting components, they are 'adaptive' entities.
R = f(c) (SYSTEM CYBERNETICS II)
NATURAL SYSTEMS: ADAPTIVE SELF-ORGANIZATION

It has been shown that ordered wholes, i.e., systems with calculable fixed forces, tend to return to stationary states following perturbations introduced into their surroundings. It is likewise possible to show that such systems 'reorganize' their fixed forces and acquire new parameters in their stationary states when subjected to the action of a physical constant in the environment.

Starting with the facts that natural systems in general go to 'ordered steady states', and that most natural system's states are relatively unstable, one could conclude that in moving from any state to a steady one, the system is going from a larger number of states to a smaller, thus performing a selection. There must be a well-defined operator (the multiplication and replacement law) which drives the system towards a specific state. Consequently all that is necessary for producing self-organization is the isolation of the "machine with input" (Asbhy 19..).

The above argument will be accepted with two modifications: (i) it is restricted to natural or synthetic, but not artificial systems (Simon 1969); and (ii) the operator drives not to a state of equilibrium in the system, but towards steady 'non-equilibrium' states. The reasons for discarding the concept of the equilibrium state in favour of the non-equilibrium steady state is: (i) equilibrium states do not have available usable energy, whereas natural systems of the widest variety do; (ii) equilibrium states are "memory-less," whereas natural systems behave in large part in function of their past histories. In short, a equilibrium system is a dead system. A machine may go to equilibrium as its preffered state, but natural systems go to increasingly organized non-equilibrium states.

Hence, the system organizes itself as a function of maximal resistance to the forces that act in its environment. It has also been shown that, starting with an arbitrary form and degree of complexity i.e., anything above
the thermodynamically most probable equilibrium
distribution, systems will complexify in response to inputs
from the environment. The evolution of an arbitrary complex
system is always in the direction of merging some
characteristics, differentiating others, and developing
partially autonomous subsystems in a hierarchical sequence.

An adapted system is optimally resistant to the kind of
forcings which elicited the process of self-organization; it
is not thereby more resistant to all factors in the general
environment. Adaptation is not synonymous with structural
stability. In fact, normally just the opposite is the case;
to the extent that adaptive self-organization occurs by
means of the complexification of structure, the system
becomes thermodynamically more "improbable" and hence
generally unstable and prone to physical disorganization.
Its increased adaptive potential derives from its higher
functional capacity, afforded by the greater degree of
freedom of the higher organizational structure. Hence
systems evolve towards increasingly adaptive, but
progressively unstable states, balancing their intrinsically
unstable complex structure by a wide range of
self-stabilizing functions.

Self-organization conduces systems towards more
information content, negentropic states; self-stabilization
maintains them in their pre-existing state of organization.
Self-organization radically modifies the existing structure
of a system and puts into question its continued self-
identity. It becomes necessary to select a more suitable
strategic level in the examination of the processes and
mechanisms of self-organizing systems, and this level is
that of the next higher suprasystem; the system formed
by the given species of systems in a shared environment.

\[ R = f(d) \] (HOLON-PROPERTY)

NATURAL SYSTEMS: INTRA- AND INTER-SYSTEMIC HIERARCHIES

Given systems which constitute ordered wholes,
adaptively stabilizing themselves in their environment to
more adapted, and normally more negentropic (or informed) states, development will be in the direction of increasing hierarchical structuration.

Both numerical and functional differences are due to hierarchical relations of the systems on the various levels; many systems on one level constitute one system on a higher level, consecutively higher level systems are less abundant and have a wider repartee of functional properties than systems on lower levels. If hierarchies are rigorously defined, they become finite trees, without loops. But, since this does not always hold true, "hierarchy" will denote a "level-structure" or a set of superimposed modules," so constituted that the component modules of one level are modules belonging to some lower level. Using the term 'system' for 'module,' we can speak of a hierarchy as a "multi-holon" type structure in which the systems functioning as wholes on one level function as parts on the higher levels, and where the parts of a system on any level (with the exception of the lowest or "basic" level) are themselves wholes on lower levels.

Systems belonging to a level below that of any chosen level are called "subsystems" in relation to the systems of the chosen level, and the system belonging to the next higher level is a "suprasystem" in relation to it.

The identification of different levels with empirically known entities is often problematic or unclear. But methodological difficulties of identification does not falsify the concepts of natural hierarchy. The hierarchy concept conserves its appeal on the basis of its supreme potential as an ordering principle, relating, through invariant hierarchical relationships, empirically dissimilar phenomena.
1.5 ARTIFICIAL SYSTEMS

Artificial phenomena are special, because a system is deliberately moulded by goals and purposes to its environment. "If natural phenomena have an air of 'necessity' about them in their subservience to natural laws, artificial phenomena have an air of 'contingency' in their malleability by environment." (Simon 1969).

The contingency of artificial phenomena often creates doubts as to whether they fall properly under science. Sometimes, these doubts are directed at their teleological character and the consequent difficulty of disentangling 'prescriptions' from 'description'. But the real problem is one of generating empirical propositions about systems that, given other circumstances, might have been quite different.

The dictionary defines "artificial" as "Produced by art rather than by nature; not genuine or natural; affected; not pertaining to the essence of the matter." In some contexts a distinction is made between "artificial" and "synthetic", as the latter may not be distinguishable from the "natural". Synthetic is often used in design, while science is more concerned with the analytic.

The need for designers to know how things "ought to be", in order to achieve "goals and functions", introduces a dichotomy between the normative and descriptive. Four indices distinguish the artificial from the natural:

1. Artificial things are synthesized by man.
2. Artificial things may imitate natural things, while lacking in some respects, the reality of the latter.
3. Artificial things can be characterized in terms of functions, goals, and adaptation.
4. Artificial things are often discussed, particularly in design, in terms of imperatives and descriptives.

Fulfillment of purpose or adaptation to a goal involves a relating among three terms, (i) the purpose or goal, (ii) the character of the artifact; its "inner" environment, and (iii) the "outer" environment in which the artifact performs. Natural science impinges at the "interface"
between the two environments. The advantage of dividing the outer from the inner environment in studying an adaptive or artificial system is that one can often predict behavior from knowledge of the system's goals and its outer environment, with only minimal assumptions about the inner environment. Often different inner environments achieve identical in similar outer environments. In very many cases whether a particular system will achieve a particular goal or adaptation depends on only a few characteristics of the outer environment and not at all on its details.

Most good designs, insulate the inner system from the environment, so that an invariant homeostatic relation is maintained between inner system and goal, independent of outer environmental variations. Such quasi-interdependence from the outer environment is maintained by (i) passive insulation, (ii) by reactive negative feedback, and (iii) by predictive adaptation.

Description of an artifact in terms of its organization structure and functioning; its interface between inner and outer environments, is a major objective of invention and design activity.

LIMITS OF ADAPTATION AND SIMULATION

Often, when one satisfies the design objectives only approximately, the properties of the inner system "show through". In a benign environment one would learn from the artifact only what it has been called upon to do, but in a taxing environment one would learn something about its internal structure, specifically about those aspects that were chiefly instrumental in limiting performance.

Artificiality connotes perceptual similarity but essential difference, resemblance from without (function) rather than within (structure). The artificial object imitates the real, by adapting similarly the outer system, relative to the same goals. "Simulation" is the imitation of a system, and its testing under a variety of simulated, or limited, environments, to gain a better understanding of the
The crucial question is: "How can simulation tell us anything that we do not already know?" There are two related ways in which simulation can provide knowledge. Even when we have correct premises, it may be very difficult to discover what they imply. But, as all correct reasoning is a grand system of tautologies, we might expect simulation to be a powerful technique for deriving from our knowledge, specific invariants, from the interaction of vast number of variables starting from complicated initial conditions, but we need the computer to work out these implications. The difficulty in design problems often resides in predicting how an assembly of such components will behave.

Can simulation be of any help to us when we do not know very much initially about the natural laws that govern the behavior of the inner system? This can be answered in the affirmative. First, we are seldom interested in explaining or predicting phenomena in all their particularity,; we are usually interested in only a few important properties.

The more we are willing to abstract from the detail of a set of phenomena, the easier it becomes to simulate the phenomena, for we have only to know those parts of it that are crucial to the abstraction. The top down construction of science was only possible through such approximate, simplified, abstractions. Resemblance in behavior of systems without identity of the inner system is particularly feasible if the aspects in which we are interested arise out of the 'organization' of the parts, independent of all but a few properties of the individual components.

SYMBOL SYSTEMS: RATIONAL ARTIFACTS

Symbol systems are goal-seeking, information-processing systems. Like the human mind and brain, the computer is another member of this important family.

Symbols are physical patterns (expressions) that can occur as components of symbol structures. A symbol system also posses a number of simple processes that, over time,
operate upon symbol structures; processes that create, modify, copy, and destroy symbols. Symbol structures can, serve as internal representations of the environments to which the symbol system is seeking to adapt. To model and reason about the environment, it must have means for acquiring information that it can be encoded into internal symbols, as well as means for producing symbols that initiate action upon the environment. Symbols may also designate processes that the symbol system can interpret, store and execute when activated.

"Computers have transported symbol systems from ideas to the empirical world of actual processes carried out by machines or brains, Simon (1969) believes them to be necessary and sufficient means for intelligent action.

THE PSYCHOLOGY OF THINKING

The apparent complexity of man's behavior when viewed over time is largely a reflection of the complexity of the environment in which he finds himself. Human behavior in problem solving, in attaining concepts, in memorizing, in holding information in short-term memory, in processing visual stimuli, and in performing tasks that uses natural languages strongly support this view.

The system is basically a serial operator, that can process only a few symbols at a time, which must be held in special, limited memory structures whose content can be changed rapidly. The relatively small capacity of short-term memory structure (7+2 chunks) and relatively long time (five seconds) required to transfer a chunk of information from short-term to long-term memory, is its organizational limit. These two limiting characteristics indicate that memory is organized in associative fashion, as "list structures".

As our knowledge increases, Simon believes, the relation between physiological and information-processing explanations will become just like the relations between solid-state physics and programming explanations in computer science. They constitute two linked levels of explanation.
with the limiting properties of the inner system showing up at the interface between them.

As we link physiology to psychology on the inner side, we can also link psychology to general theory of search through large combinatorial spaces on the outer side; the task environment. The theory of design is this general theory of search.

REMEMBERING AND LEARNING

In the past few decades researchers in both cognitive psychology and artificial intelligence has been turning more and more to semantically rich domains, where skillful performance calls upon large amounts of specialized knowledge retrieved from memory.

A few parameters, especially the chunk capacity of STM and the storage time for new chunks in LTM play a dominant role in fixing the limits of the system’s performance.

The decision-making process operates on an outer environment that has two major components: the "real world," sensed and acted upon, and a large store of (correct and incorrect) information about the world, stored in long-term memory and retrieved by recognition or by association. When the processor is solving puzzle like problems, the memory plays a limited role. The structure of the problem rather than the organization of memory steers the problem-solving search. When it is solving problems in semantically rich domains, a large part of the problem-solving search takes place in long-term memory and is guided by information discovered in the memory. Hence an explanation of problem solving in such domains must rest on an adequate theory of memory.

The memory is usually described as "associative" because of the way one thought retrieved from it lead to another. Information is stored in linked list structures. Long-term memory operates like a second environment, parallel to the external environment, through which the problem solver can search and to whose contents he can
respond. Information gleaned from one environment is used to guide the next step of search in the other.

Memory has been discussed here as though it consisted mainly of a body of 'data'. But experts possess skills as well as knowledge. The boundary between knowledge and skills is subtle, as expertise can be stored as data or process (for drawing inferences from it), or some combination of both.

A scientific account of human cognition describes it in terms of several sets of invariants. First, there are the parameters of the inner environment. Then, there are the general control and search-guiding mechanisms that are used over and over again in all task domains. Finally, there are the learning and discovery mechanisms that permit the system to adapt with gradually increasing effectiveness to the particular environment in which it finds itself. The adaptiveness of the human organism, the facility with which it acquires new strategies and becomes adept in dealing with highly specialized environments, makes it an elusive and fascinating target; and the very prototype of the artificial.
1.6 TOPICS IN THE THEORY OF DESIGN

Design is the core of all professional training, which distinguishes the professions from the sciences. Their central concern is the process of design, but for this both the natural and artificial sciences are necessary.

THE FORMAL LOGIC OF DESIGN:

1. Since the concern of standard logic is with declarative statements, it is well suited for assertions about the world and for inferences from these assertions. Design on the other hand, is concerned with how things ought to be; with devising artifacts to attain goals. Various paradoxes have been constructed to demonstrate the need for a distinct logic of imperatives, or a normative deontic logic. But as it can be shown that a modest adaptation of ordinary declarative logic is sufficient, a special logic of imperatives is unnecessary.

Design solutions are a sequence of actions that lead to possible worlds satisfying specified constraints. With satisficing goals the sought-for possible worlds are seldom unique; the search is for 'sufficient', not 'necessary', actions for attaining goals.

THE EVALUATION OF DESIGN:

2. THEORY OF EVALUATION:

There exists a considerable area of decision practice such as the so-called "optimization methods" of probability and utility theory and their intersection, where standards of rigor in inference are as high as one could wish.

The logic of optimization methods can be sketched as follows: The "inner environment" of the design problem is represented by a set of given alternative actions. The alternatives may be given 'in extensio'; or more commonly described in terms of 'command variables' that have defined domains. The "outer environment" is represented by a set of parameters, which may be known with certainty, or only in terms of a probability distribution. The goal for adaptation
of inner to outer environment are defined by a utility function; usually scalar, of the command variable and environmental parameters, usually supplimented by a number of constraints; inequalities, say between functions of the command variable and the environmental parameters. The optimization problem is to find an admissible set of values of the command variables, compatible with the constraints, that maximize the utility function, or its expected value, for the given value of the environmental parameters.

Since the optimization problem, once formalized, is a standard mathematical problem, the answer rests on the standard logic of predicate calculus. The method first considers all possible worlds that meet the constraints of the outer environment; then finds the particular world in the set that meets the remaining constraints of the goals and maximizes the utility function.

3. COMPUTATIONAL METHODS:

This includes the body of techniques for actually deducing which of the available alternatives is the optimal.

(i) Algorithms for choosing 'optimal' alternatives such as linear programming computations, control theory, and dynamic programming.

The subject of computational techniques need not be limited to optimization. Traditional engineering design methods make much more use of inequalities, i.e., that of maxima and minima. Comparison is between "better" or "worse" and seldom provides a judgement of the "best".

(ii) Algorithms and heuristics for choosing 'satisfactory' alternatives.

THE SEARCH FOR ALTERNATIVES:

4. HEURISTIC SEARCH:

Now in many satisficing situations, the expected length of search for an alternative meeting specific standards of acceptability, hence performance depends on how high the standards are set, but it hardly depends on the size of the
total universe to be searched. Hence when we use satisficing methods, it often does not matter whether or not the total set of admissible alternatives is "given" by a formal impracticable algorithm.

In the case of optimization we ask: "Of all possible worlds, which is the best?" And when we are seeking a satisfactory alternative, once we have found a candidate we can ask: "Does this alternative satisfy all the design criteria?" Clearly both question raises no new issues of logic. But what about the process of searching for a candidate?

One must be able to represent differences between the desired and the present. To behave purposefully one must be able to select from time to time those particular actions that are likely to remove the particular difference between desired and present states that the system detects. This selection is achieved through a 'table of connections', which associates with each kind of detectable difference and those actions that are relevant to removing those differences. Since reaching a goal requires a sequence of actions, and since some attempts may be ineffective, it must also have means of detecting the progress it is making, and for trying alternative paths.

Since we have imperfect knowledge about the relations of actions to change in the situation, this becomes a question of choice under 'uncertainty'.

It is characteristic of a search that the solution, the complete actions that constitute the final design, is built up from a sequence of component actions. Its validity requires some strong assumptions about the interdependence of the effects of the several actions on the several differences. One might say that the reasoning is valid in worlds that are "additive" or "factorable" in a certain sense. Nonadditive actions can result in increasing or decreasing returns.

Actions have side consequences and sometimes can only be taken when certain side conditions can be satisfied. Under
these circumstances one can never be certain that a partial sequence of actions that accomplishes 'certain' goals can be augmented to provide a solution that satisfies all the conditions and attains all the goals of the problem.

For this reason problem-solving systems and design procedures in the real world do not merely 'assemble' problem solutions from components but must 'search' for appropriate assemblies. In carrying out a search, it is often efficient to begin to explore several tentative paths, continuing to pursue a few that look most promising at a given moment. If one of the active parts begins to look less promising, it may be replaced by another that previously had been assigned a lower priority.

Generally, the "promise" of a plan can be represented by a probability distribution of outcomes that would ensure if it were pursued to completion. The distribution once estimated, can be used within the framework of Bayesian decision theory, or other satisfactory method of valuation.

In typical problem structure, a problem-solving program begins to search along possible paths, storing in memory a "tree" of the paths it has explored. Attached to the end of each branch; each partial path, is a number that is supposed to express the "value" of the path. Values can be thought of as the gain expected from further search along the path, and must not be confused with the "probability" that the path would lead to a desired solution. For, very often a higher value may be associated with a path, that has only a low probability of leading to the desired solution.

Recognizing the importance of assigning values to incomplete paths, to guide the choice of the next point of exploration, it is natural to generalize even further, and evaluate all kinds of significant information at each step in the search, such as the consequent values of alternate search paths.

Thus search processes can be viewed as processes for seeking a problem solution. But they can be viewed more generally as as processes for gathering information about
problem structures that will ultimately be valuable in discovering a problem solution.

The exploration of parallel, or near-parallel, factorizations of differences. 'Means-end analysis' is an example of a broadly applicable problem-solving technique that exploits this factorization.

5. THE ALLOCATION OF RESOURCES.

There are two ways in which design processes are concerned with the allocation of resources. First, conservation of scarce resources may be one of the criteria for a satisfactory design. Second, the design process itself involves management of the resources of the designer so that his efforts will not be dissipated unnecessarily in following lines of enquiry that prove fruitless.

There is nothing specific that need be said here about resource conservation; cost minimization (cost-benefit analysis), for example, as a design criteria.

THEORY OF STRUCTURE AND DESIGN ORGANIZATION:

6. HIERARCHIC ORGANIZATIONS.

The organization of complex structures and its implications for the organization of design processes.

As complex systems are constructed in a hierarchy of levels, one powerful technique of design is to discover ways of decomposing it into semi-independent components corresponding to its many functional parts. The design of each component can then be carried out with some degree of independence of the design of the others.

There is no reason to expect that the decomposition of the complete design into functional components will be unique. In important instances there may exist alternate feasible decompositions of radically different kinds. Much of classical organizational theory in fact was concerned precisely with this issue of alternate decomposition of a collection of interrelated tasks/functions.

To take a greatly oversimplified example of a
"generate-test cycle", a series of generators may generate one or more possible outlines and schemes of fenestrations for a building, while tests may be applied to determine whether needs for particular kinds of rooms can be met within the outlines generated. Alternatively the generator may be used to evolve the structure of rooms, while tests are applied to see whether they are consistent with an acceptable over-all shape and design. Buildings can be designed from outside-in or from inside-out.

Alternatives are also open, in organizing the design process, as to how far development of possible subsystems will be carried before the over-all coordinating design is developed in detail, or vice-versa, how far the over-all design should be carried before various components, or possible components are developed. Such alternatives to design are familiar to architects.

A theory of design will include principles for deciding such questions of 'precedence' and 'sequence' in the design process.

When we recall that the process will generally be concerned with finding a satisfactory design, rather than an optimum design, we see that the sequence and the division of labour between generators and testers can affect not only the efficiency with which resources for designing are use, but also the nature of the final design as well. What we ordinarily call "style" may stem just as much from these decisions about the design process as from alternate emphasis on the goals to be realized through the final design.

Variety within the limits of satisfactory constraints, may be a desirable end in itself, among other reasons, because it permits us to attach value to the search as well as its outcome; to regard the design process as itself a valued activity for those who participate in it.

Thus, both the shape of the design and the shape and organization of the design processes are essential components of the theory of design.
7. ALTERNATE REPRESENTATIONS

Alternative representations for design problems, skills of constructing organizations as frameworks for problem representation, building representations around limiting factors, and representing non-numerical problems.

Problem representation has an important influence on design. Problem solving involves change in representation. All mathematics exhibits in its conclusions only what is already implicit in its premises. Hence all mathematical derivations can be viewed simply as change in representation, making evident what was previously true but obscure. This view can be extended to all problem solving; solving a problem simply means representing it so as to make the solution transparent.

Since much of design, is concerned with objects or arrangements in real Euclidean two-dimensional or three-dimensional space, the representation of space and of things in space will necessarily be a central topic in a science of design.

An early step towards understanding any phenomena is to learn what kinds of things there are in a set; to develop a taxonomy.

In a completely pragmatic vein we know that problems can be described verbally, in natural language. (i) They often can be described mathematically, using standard formalism of algebra, geometry, set theory, analysis, or topology. (ii) If the problem relates to physical objects, they or their solutions can be represented in drawings, renderings, or three-dimensional models. (iii) Problems that have to do with actions can be attacked with flow charts and programs. Other models of representation may also exist.

THE DESIGN OF EVOLVING ARTEFACTS:

8. BOUNDED RATIONALITY

Bounded rationality. The meaning of rationality in
situations where the complexity of the environment is immensely greater than the computational powers of the adaptive system.

Finding the limiting resource. A design representation suitable for a world in which the scarce factor is ‘information’ may be exactly the wrong one for a world in which the scarce factor is ‘attention’.

Representation without numbers. Numbers are not the name of this game but rather representational structures that permit functional reasoning, however qualitative it may be.

If, given a good problem representation, rational analysis can sometimes be carried out even in the absence of most of the relevant numbers, still we should not make a virtue of this necessity. The quality of design is likely to depend heavily on the quality of the data available. The task is not to design without data, but to incorporate assessments of the quality of the data, or its lack of quality, in the design process itself.

What paths are open to us when we must plan in the face of extremely poor data? One minimal strategy, is to associate with every estimated quality a measure of its precision. Labelling estimates in this way does not make them more reliable, but does remind us on how hard or soft they are and hence how much trust to place in them.

9. DATA FOR PLANNING

Methods of forecasting, the use of predictions and feedback in control.

Data about the future (prediction), are commonly the weakest point in the armor of facts. Good predictions have two requisites that are often hard to come by. First, they require either a theoretical understanding of the phenomena to be predicted, as a basis of the predictive model, or phenomena that are sufficiently regular that they simply be extrapolated. The second requisite for prediction is having reliable data about the initial condition; the starting point from which the prediction is made. Since the
consequence of design lie in the future, it would seem forecasting is an unavoidable part of every design process.

The heart of the data problem is not forecasting but constructing alternate scenarios for the future and analysing their sensitivity to errors in the theory and the data. There is no need to construct detailed forecasts for each of these perspectives. Instead we can concentrate our analytic resources on examining alternate target states for the system for the short, middle, and long run. Having chosen a desirable (or acceptable) target state, and having satisfied ourselves that it is realizable; is not unduly sensitive to unpredictables, we can turn our attention to constructing paths that lead from the present to the desired future.

Designing for distant futures would be wholly impossible if remote events have to be envisioned in detail. What makes such designs even conceivable, is that we need to know or guess about the future only enough to guide the commitments we must make today.

Few of the adaptive systems that have been forged by evolution have been forged by evolution or shaped by man depend on prediction as their main means of coping with the future. Two complimentary mechanisms for dealing with change in the external environment are often far more effective than prediction: 'homeostatic mechanisms' that make the system relatively insensitive to the environment and 'retrospective feedback adjustments' to the environment's variations.

Homoeostatic mechanisms are especially useful for handling short-range fluctuations in the environment, hence for making short-range predictions unnecessary.

Feedback mechanisms, on the other hand, by continually responding to discrepancies between a system's actual and desired states, adapt it to long-range fluctuations in the environment without forecasting. In whatever direction the environment changes, the feedback adjustments track it, with of course some delay.
In the domain where some reasonable degree of prediction is possible, a system's adaptation to its environment can usually be improved by the combining predictive control with homeostatic and feedback methods. It is well known in control theory, however, that feedforward controls, using prediction, can throw a system into undamped oscillation unless the control responses are carefully designed to maintain stability. Because of the possible destabilizing effects of taking inaccurate predictive data too seriously, it is sometimes advantageous to omit predictive data entirely, relying wholly on feedback, unless the quality of the prediction is high.

10. PROFESSIONAL RELATIONS

Identifying the client. Professional-client relations, society as the client, the client as playing in a game.

At microsocial levels of the design it is tacitly assumed that the professionals work for a specific client, and that the needs and wishes of the client determines the goals of the professional's work.

Thus the traditionally definition of the professional's role is highly compatible with 'bounded rationality', which is most comfortable with problems having clear-cut and limited goals. But as knowledge grows, the role of the professional comes under question. Developments in technology give professionals the power to produce larger and broader effects, at the same time they become more clearly aware of the remote consequences of their prescriptions.

In part this complication in the professional's role comes about simply as a direct by-product of the growth of knowledge. Whether through the modification of professional norms or through direct interventional of government, new obligations are placed on the professional to take account of the external effects; the consequences beyond the clients concern, that are produced by the design.

These same developments cause the professional to
redefine the concept of the client. As societies and governments take on wider range of responsibilities, more and more professionals find they no longer serve individual clients, but are employed directly by agencies or the state.

Architects are especially conflicted for several reasons. First, they have always assigned themselves the dual role of artist and professional, two roles that often make inconsistent demands. And secondly, they often assume the responsibility for complex problems involving the design of social systems, for which they are seldom adequately equipped.

Other problems of an ethical nature are that of 'resource allocation' or how to balance costs versus benefits, and 'transfer pricing' or whether to subsidise services or not.

In the traditional professional-client relation, the client's needs and wants are given. The environment is to be adapted to the client's goals, not the goals to the environment. Yet much utopian thought has consieved of changes in both directions. Society was to be made fit for human inhabitation, but the human inhabitants were also to be modified to make them more fit for society. Today we are in deep conflict about how far we should go in "improving" human beings involuntarily.

In professional environments there is continuing potential for conflicts between decisions criteria defined by the profession and those enforced by an authority or organization.

In any planning whose implementation involves a pattern of human behavior, the behavior must be motivated. Knowledge that "it is for our good" seldom provides adequate motivation (Maszlow 1951).

Organization theory deals with this motivation question by examining organizations in terms of the balance between the 'inducement' that are provided to the members to perform their organizational roles and the 'contributions' that the
members thereby provide to teh achievement of organizational goals. This is not dissimilar to the games between the planners and those whose behavior they seek to influence (transactional analysis and game theory) and the intricacies of the various modes of participative planning (cost-benefit analysis).

11. TIME AND SPACE HORIZONS.

The discounting of time, defining progress, managing attention.

The events and prospective events that enter into our value system are all dated, and the importance we attach to them generally drop off sharply with their distance in time. For the creatures of bounded rationality that we are, this is fortunate. For if this were not so, we would never be able to make a decision in time, for we would be forever lost in thought.

Our unconcern with the distant future is not merely a failure of empathy but a recognition that (i) we shall probably not be able to foresee and calculate the consequences of our actions for more than short distance into the future and (ii) those consequences will in any case be diffuse rather than specific.

The important decisions we make about the future are primarily the decisions about spending and saving, about how we shall allocate our production between present and future satisfaction. And in saving, we count flexibility among the important attributes of the objects of our investment, because flexibility ensures the value of these investments against the event that will surely occur but which we cannot predict. It will (or should) bias investment in the direction of structures that can be shifted from one use to another, and to knowledge that is fundamentally enough not to be outmoded; knowledge that may itself provide a basis for continuing adaptation to the changing environment.
12. NO FINAL GOALS

Designing without final goals. Designing for future flexibility, design activity as goal, designing an evolving system.

Planning and decision making procedures deal with remote effects. Defining what is meant by progress in human societies is not easy. (i) Increasing success in meeting basic human ‘needs’, is what most would agree upon. (ii) Another would be an average increase in human ‘happiness’. (iii) A third way in measuring human progress is in terms of intentions rather than outcomes, which might be called ‘moral’ progress. Moral progress has always been associated with the capacity to respond to human values. It can be argued that growth of knowledge can represent such moral progress. Rationality applied to a broader domain will simply be a more calculated rational selfishness (egoism) rather than the impulsive selfishness (altruism) of the past.

From a pragmatic standpoint we are concerned with the future because securing a satisfactory future may require actions in the present. Any interest in the future that goes beyond this call for present action has to be charged to pure curiosity.

The idea of final goals is inconsistent with our limited ability to foretell or determine our future. The real results of our actions is to establish initial conditions for the next succeeding stage of action. What we call "final" goals are in fact "criteria" for choosing the initial conditions that we will leave to our successors.

How do we want to leave the world for the next generation? One desideratum would be a world offering as many alternatives as possible to future decision makers, avoiding irreversible decisions that they cannot undo.

A second desideratum is to leave the next generation of decision makers a better body of knowledge and a greater capacity for experience.
1.7 METHODOLOGICAL PROBLEMS

THE MORPHOLOGICAL APPROACH

Zwicky (1969) points out that if the values of principles are not recognized, no one benefits. Hence identifying the nature of such causes and instituting remedies is essential to avoiding oversights. Further, as prediction requires a correct world image, and as cumulative knowledge of the 'outer world', and insights into many 'inner worlds' exists, this store of knowledge must contain important pieces of information that are not known, and others that are as yet unknown. The task of the morphologist is to find these missing links to satisfactorily complete our world image.

The approach proposed is the 'complete field coverage' or exhaustive exploration of all domains. The morphological method starts from fixed points, or reliable 'pegs' of previously available knowledge and infiltrates and extrapolates from unexplored domains.

Classes of problems:
1. Problems for whose solution only small number of pegs of knowledge need be known.
2. Problems for whose solution pegs of knowledge are necessary that are as yet unavailable.
3. Problems that involve a great number of parameters.

Methods of solving:
1. Formulating the problem.
2. Scrutiny of the essential parameters of the problem.
3. Establish and study the interrelationships.
4. Application of the morphological box/approach.
5. Method of successive approximation and continuous feedback.

Structures can be investigated by analysis or synthesis. Often dissection or analysis is much easier than construction or synthesis, which in many instances has not yet been achieved. The class of problem and the state of search determines the appropriate approach.
TYPES OF RELATIONS

Ranking is a way of relating some or all of the elements in a set. A relation is 'reflexive' if it holds between a thing and itself; it is 'symmetric' if, when it relates one thing to a second, it similarly relates the second to the first; it is 'transitive' if, when it holds between one thing and a second and between the second and the third, it also holds between the first and the third; and finally it is 'connective' over a set of elements if it applies to every set of these elements taken in one order or another.

A binary relation is called:

1a. Reflexive if every dot in
   its graph has a loop attached;
1b. Irreflexive if no dot in its
   graph has a loop attached;
1c. Non-reflexive if it's neither
   reflexive nor irreflexive;
2a. Symmetric if no arrow in its
   graph is single;
2b. Asymmetric if no arrow in its
   graph is double;
2c. Non-symmetric if it's neither
   symmetric nor asymmetric;
2d. Antisymmetric if it's neither
   symmetric, asymmetric nor non-symmetric;
3a. Transitive if its graph contains no
   broken journeys without a short cut;
3b. Intransitive if its graph contains no
   broken journeys with a short cut;
3c. Non-transitive if it's neither
   transitive nor intransitive;
4a. Connected if in its graph, any two dots
   are connected in one direction or the
   other (or both);
4b. Not connected.
TYPES OF ORDERING

The elements of a population may be ordered in various ways depending on the properties of the ordering relation. These orderings range from the "weak" to the "strong".

Essential to any type of ordering is the ability to differentiate between elements by establishing one-directional differences. Hence ordering requires a relationship that is not symmetric; that is, one that is either asymmetric, nonsymmetric, or antisymmetric.

A relation which is either nonsymmetric or asymmetric and which does not hold between all elements of the population (i.e., is nonconnected) provides the weakest type of ordering.

The ordering strengthens if the relation holds between all pairs of different elements of the population, that is if the relation is connected.

A relation which is transitive and symmetric allows us to form chains of similar things, but not to order them.

A 'weak' ordering or ranking is formed by a reflexive, antisymmetric, transitive, and connected relation.

A 'partial' ordering or ranking is formed by a relation which is reflexive, antisymmetric, transitive, and nonconnected.

A 'complete' ordering or ranking is formed by a irreflexive, asymmetric, transitive, and connected relation.

Numbers are usually assigned to order elements to represent their rank. In the case of a partial ordering this is of little value, since some of the elements cannot be ranked.
MEASUREMENT: SYSTEMATIC SCALING AND WEIGHTING

As definition and measurement are both procedures used to establish order, a discussion of one will almost inevitably involve the other. With such functional similarities, it is not surprising that at times, they even appear to be the same thing.

"Measurement... (is used to) designate the procedure by which we obtain symbols which can be used to represent the concepts to be defined." The term measurement is frequently applied to any process that assigns numbers to objects, events or properties. But a symbolic representation of the concept defined is not necessary measurement. "The purpose of measurement is to represent the content of observations by symbols which relate to each other in the same way that the observed objects, events or properties are or can be." (Ackoff 1962).

Clearly if we want to manipulate the symbols, numbers are the easiest to use, but we must in all cases make explicit what operations may be made on them. Rules can also be set down for performing the equivalent operations on other types of symbols.

Measurements allow us, (i) to compare the same properties of different things, and (ii) the same properties of same things at different times, and (iii) to describe how properties of same or different things are related to each other.

Measurement can be defined functionally as the way of obtaining symbols to represent the properties of objects, events, or states, which symbols have the same relationship to each other as do the things which are represented.
SYSTEMATIC UNIDIMENSIONAL SCALING OF MEASUREMENTS:

NOMINAL (NAMING) SCALE
Determination of equality. Only identifies members (names)
No quantitative relationships. Neither is there any order.
Permutation group.
\[ x' = f(x) = \text{any one to one substitution} \]
   e.g.: red, black, blue, white. Random mapping.

ORDINAL (RANKING) SCALE
Determination of greater or lesser. Compares attributes.
Indicates the order. No quantitative relationships.
Isotonic group.
\[ x' = f(x), \text{ where } f(x) = \text{any increasing monotonic function} \]
   e.g.: bad, fair, good, v.good. Semantic differential.

INTERVAL (DIFFERENCE) SCALE
Determination of the equality of intervals or differences.
Preserve order and specifies degree of difference.
No natural interval. No natural origin.
Linear or affine group.
\[ x' = a.x + b, \text{ where } a > 0 \]
   e.g.: -3a+b, -2a+b, -a+b, +b, +a+b, +2a+b, +3a+b...
   Celsius and Farenheit Thermometer scales.

RATIO SCALE
Determination of the equality of ratios.
Preserves interval difference.
No natural interval. Natural origin.
Similarity group.
\[ x' = c.x, \text{ where } c > 0 \]
   e.g.: -3c, -2c, -c, 0, +c, +2c... Linear measuring scale.

ABSOLUTE (FUNDAMENTAL OR ADDING) SCALE
Determination of absolute quantity.
Natural interval. Natural origin.
\[ x' = x + 1, \text{ or } x - 1 \]
   e.g.: -3, -2, -1, 0, +1, +2, +3... (unique)
   Natural counting measure

From Stevens (1951) and Kim (1981).
The basic operations needed to create a given scale are
listed just below its name. In the mathematical
transformations that leave the scale form invariant, any
number \( x \) on a scale can be replaced by another number \( x' \),
where \( x' \) is the listed function of \( x \).
To make a finer gradation, some classifications also
include the logarithmic interval scale.
WEIGHTING IN SYSTEMS DESIGN

Decisions that must rest on a balance among several different criteria are the norm in real-world design and planning.

Decisions necessitate judgements about alternatives (weighting), which must be aggregated from partial judgements (scaling) of individual criteria (parameters, objectives or aspects).

Conceptual subsystems are built up of scaled partial judgements. Conceptual systems are built up on weighted relations of these subsystems. They in turn can be subject to scaling and relative weighting to form higher concepts.

Thus at any hierarchy of a conceptual or physical system, the origins can be traced through either the higher and/or the lower constructs, depending on the complexity of the interrelationships.

Design objectives (> process) and planning decisions (> process) can thus be matched (made to coincide), by adjusting the weightages, or by using more precise definitions of relationships, or by using more objective scales, as close to the absolute as possible.

THE PROBLEM OF WEIGHTING

Weighting is the problem of representing two or more conceptual subsystems by means of a common scale.

Translation (mapping) of any subsystem of concepts is difficult unless they can identified as members under a nominal scale (list of names).

Even if the subsystems are represented on the same type of scale, the scales may be measuring different things (attributes).

Even if the scales measure the same attributes, the attributes may have different degrees of importance (weightages).

The problem then becomes one of selecting a suitable scale for the weighting procedure. The conceptual subsystems are then represented on the selected scale.
The process is then repeated for each higher subsystem, or reversed and repeated for each lower subsystem to arrive at a decision.

Normally, depending on the nature of the problem, there is a balance between objective (relatively certain) and subjective (intuitive) modes of evaluation (weighting). The point of transition from subjective to objective modes depends on the degree of knowledge (hard and soft) available, hence the nature of the problem (predominantly tame or wicked).

Conflicts arise when objective weighting procedures are used to evaluate conceptual subsystems on subjective scales (nominal or ordinal), or where subjective weighting procedures are used to evaluate conceptual subsystems that are on a more objective scale (interval, ratio, or absolute).

Analysis (of wicked problems) often necessitates the use of the former method. The degree of certainty would thus depend on the conceptual thought (evaluative) level at which the subjective scale is used.

Decisions are usually made on the basis of the latter. The degree of uncertainty or risk would then rest on the objective precision of the knowledge base of the problem set or subsets (lists).

DETERMINISTIC AND PROBABILISTIC CAUSALITY, AND CORRELATION

When one phenomena, X, is said to cause another, Y, several different things may be ment:
1. X is necessary and sufficient for Y,
2. X is necessary but not sufficient for Y,
3. X is known to be either necessary or sufficient for Y, but they tend to be either present or absent together.

The first of these is 'deterministic' causality (cause-effect), the second is 'probabilistic' or nondeterministic (producer-product), and the third is 'correlation' and may not involve causality at all.

Correlational analysis enables us to measure the tendency of
variables to change or not to change their values together.

DECISION UNDER CERTAINTY, RISK OR UNCERTAINTY

The field of decision making is commonly partitioned according to whether it is effected under conditions of certainty, risk, or uncertainty.

1. 'Certainty' if each action is known to lead invariably to a specific outcome.

2. 'Risk' if each action leads to one of a set of possible outcomes, each outcome occurring with a known probability. These probabilities are assessed to be known by the decision maker.

3. 'Uncertainty' if either action or both has as its consequence a set of possible specified outcomes, but where the probabilities of these outcomes are completely unknown or not even meaningful.

For considering the various types of problems it is necessary to clarify the meanings of such expressions as 'quantitative' and 'qualitative objectives', 'course of action', and 'efficiency'.

QUANTITATIVE AND QUALITATIVE OBJECTIVES

A qualitatively defined outcome is one which, following the choice of a course of action, is either obtained or not. There are no in "betweens".

A quantitatively defined outcome is one which is (or is not) obtained in various degrees. A quantitatively defined outcome is really a set of objectives differentiated from each other by values along a specified scale.

COURSE OF ACTION

A course of action is not to be construed as a mechanically specified pattern of behavior. Variations in the action with respect to certain physical characteristics may not change the course of action. A course of action and its outcome are conceptual constructs which can be converted into each other, depending on the decision makers.
intensions. Hence they are relative terms, that normally imply simple-choice. When the selection of procedures or rules permits the selection of a course of action in a specified context, then the procedure itself is a course of action and is called a strategic-choice. There are also situations where a decision maker does not directly select a course of action.

MEASURE OF EFFICIENCY

There are several types of measure of efficiency, the definition of which requires the concept of 'inputs' and 'outputs'. 'Inputs' refer to the resources (any that can be valued) which are consumed or expended in taking a course of action. 'Outputs' may be measured in terms of either the resources which result from taking the course of action or the psychological or sociological characteristics of the resulting state.

Outcomes and hence objectives may be defined in terms of either input or output, or both. The type of measure of efficiency required depends on whether the amount of input and/or output are specified or are variable in the definitions of the relevant outcomes. This leads to four possible types or measures of efficiency. If we determine that relative frequencies with which the relevant inputs and/or outputs occur over time, we can formulate a probability-density function of these outcomes, which can be called the 'efficiency function'.
1.8 CONCLUSION: SYSTEMS

The various philosophies of the natural science provide useful interpretations of design methods and assist in formulating alternate problem-solving techniques. Besides defining process continuums, they clarify dichotomies and circumvent the tautological problems of epistemology. But most concepts become increasingly relative, as the limitations of absolute definitions are discovered.

Systems thinking, or the synthetic mode of thought is expansionistic and teleological in intent, whereas analytic thinking is reductionist and mechanistic. As synthetic thinking leads to purposeful systems that are increasingly automated, their organization and control pose new and complex problems of a multidimensional character.

General systems theory assists in discovering and explaining such complexities. It achieves this through second-order models of organization and the identification of relational entities and their interfaces, thus facilitating evaluation of a systems performance.

The characteristic properties of Natural systems are wholeness and order, adaptive self-stabilization or the ability to adjust and change functions, adaptive self-organization or dual function-structure changes, and the Holon property of intra- and inter-systemic hierarchies with their corresponding interrelations.

Artificial systems have contingent characteristics because of their synthetic origins. To predict their performance, often knowledge of the systems goals and outer environment will suffice. Good systems have a homeostatic relation between inner system and goal, that is independent of the outer environment.

Topics in the theory of design can be treated more effectively when interpreted in these terms. Often problems that are encountered can only be satisfied and not optimized. A systems approach permits such satisfying options to be externalized.

Certain methodological problems can also be effectively
reinterpreted. The systems approach thus also assist in setting the criteria for decision making.
ON DYNAMICS

2.0 INTRODUCTION
2.1 THEORY OF DYNAMIC SYSTEMS
2.2 DYNAMIC PROCESSES
2.3 SYSTEMS BUILDING
2.4 SYSTEMS PERFORMANCE
2.5 BUILDING DYNAMICS
2.6 DYNAMIC SHIFTS
2.7 CONCLUSION
2.0 INTRODUCTION: DYNAMICS

"... in 1922 I ordered by telephone from a sign factory five paintings in porcelain enamel. I had the factory's color chart before me and I sketched my paintings on graph-paper. At the other end of the telephone the factory supervisor had the same kind of paper divided into squares. He took down the dictated shape in the correct position." As narrated by Moholy-Nagy (1949), recounting the creation of a group of paintings.

Dynamics is "the physical, intellectual or moral force that produces motion, activity, change or progress in a given sphere". This section will deal with the dynamic processes of systems building. Two aspects will be stressed. The information necessary for the systems building process, and the necessity of controls over time dependent relationships or interfaces.
2.1 THEORY OF DYNAMIC SYSTEMS

As natural systems are created by evolution and not by design, man adapts without feeling compelled to understand them. But when they became complex or artificial and their behaviors seem confusing, no general theory will appear possible. Then the need for orderly structures, cause and effect relations, and a theory to explain systems behavior, will be felt.

The barrier to understanding systems is not the absence of important general concepts, but only the difficulty in identifying and expressing the body of universal principles that explains the success and failure of the system of which we are a part.

A structure or theory is essential if we are to effectively interrelate and interpret our observations in any field of knowledge. A systems structure should give to education in human affairs the same impetus that the structure of physical laws have given to technology. Structure is able to narrow down the gap between advanced knowledge and elementary knowledge.

Systems can be classified as open systems and closed systems. An open system is one characterized by outputs that respond to inputs, but where the outputs are isolated from and have no influence on the inputs. An open system is not aware, and hence cannot observe or react to its own performance. In an open system past actions do not control future actions, there is no feedback. A building is an open system which by itself is not governed by its past use, nor does it have a goal as to its future use.

A closed system, is a feedback system as it is influenced by its past behavior. A feedback system has a closed loop structure that brings results from past actions of the system to control future actions. A negative feedback system seeks a goal and responds as a consequence of failing to achieve that goal. Positive feedback systems generate growth processes wherein action builds a result that generates still greater action.
A feedback system controls actions based on the results of previous actions. The heating system of a house is controlled by a thermostat which responds to the heat previously produced by the furnace. Because the heat already produced by the system controls the forthcoming generation of heat, the heating system represents a negative feedback system that seeks the goal of proper temperature. If a building component under the action of weather deteriorates and is unattended, the condition will speed up further deterioration. In this positive feedback system the deterioration rate depends on, but is not controlled by the previous deterioration state.

Whether a system should be classified as an open system or a closed system is not intrinsic to the particular assembly of parts but depends on the observer’s viewpoint in defining the purpose of the system. An open system can be viewed as a structural or organizational concept, whereas a closed system can be viewed as a functional or teleological concept. It is the positive feedback form of system structure that one finds the force of growth. It is the negative feedback, or goal-seeking, structure of systems that one finds the cause of fluctuation and instability.

FEEDBACK DYNAMICS

Figure 2.1.1 shows the basic cause-and-effect structure of a feedback loop. It is a closed path, connecting in sequence the decision that controls action, the "level" of the system, and information about the level of the system, the latter returning to the decision making point.

The term level is used to mean a state or condition of the system. The available information, as it exists at any moment, is the basis for the current decision that controls the action stream. The action alters the level of the system. The "true level" of the system is the generator of information about the system, but the information itself may be late or erroneous. The information is the "apparent level" of the system which may differ from the true level.
Fig. 2.1.1
Feedback loop.

Fig. 2.1.2
Dynamic behaviors.
It is the information, not the true level, that is the basis of the decision process. Information is sometimes good enough that no distinction is necessary between true and apparent level.

The interplay of activity within "negative" feedback loops can range from smooth achievement of the goal that the loop is seeking, to wild fluctuations in search of the goal. "Positive" feedback loops show growth or decline. "Nonlinear" coupling can cause a shift of dominance from one system loop to another. The dynamic or time-varying behavior of feedback loops, can be mapped by curves showing the changing value of some system variable as time progresses. Figure 2.1.2 illustrates some characteristic responses over time.

Curve A is typical of the simplest kind of feedback system in which the variable rises at a decreasing rate towards a final value. Such a simple approach to equilibrium is experienced when end conditions are known, and is caused by the decreasing discrepancy between present and final value.

Curve B shows trial and error oscillations as the system overshoots the final value, then falls below in trying to recover from the earlier overshoot. Such behavior can result from excessive time delays in the feedback loop or from too violent an effort to correct a discrepancy between apparent system level and system goal.

Curve C shows growth where there is, in each succeeding time interval, the same fractional increase in the variable. This is an example of exponential growth.

Curve D shows initial exponential growth followed by a leveling out. The latter occurs due to some resource constraint.

Figure 2.1.3 is the simplest structure to be found in a feedback loop. It is a First-Order, Negative-Feedback Loop. A single decision controls the input to one system. There is no delay or distortion in the information channel going from the level to the decision, i.e., assumed and actual system
Fig. 2.1.3
First-order negative feedback.

Fig. 2.1.4
Second-order negative feedback.

Fig. 2.1.5
Positive feedback.
level match. A negative feedback loop is a loop in which the control decision attempts to adjust some system level to a value given by a goal introduced from outside the loop. The negative feedback loop implies some algebraic sign reversal in the decision process, as a rising level produces a decisions to decrease.

A Second-Order, Negative-Feedback Loop, Figure 2.1.4, has two level variables. The second level introduces a delay or distortion in information feedback which influences both stages of decisions, hence inducing oscillations in both the levels of the system.

The Positive-Feedback Loop in Figure 2.1.5, does not seek an externally determined goal as does the negative-feedback loop. Instead the positive loop diverges or moves away from the goal. The positive loop does not have the reversal of sign in traversing the loop that is found in the negative loop. Action within the positive loop increases the discrepancy between the systems level and a goal or reference point.

Growth processes show positive feedback. But exponential growth reaches overhelming proportions if unchecked. But growth interacts with parts of the surrounding system to modify the growth process. Such growth towards a limit, can be represented by a Coupled Nonlinear Feedback Loop.

Models of such feedback loop systems lend themselves well to simulation, and give usefull information about the dynamic, that is, time-varying behavior of the real system that the model represents.

STRUCTURE OF SYSTEMS

The structure of a subject guides us in organizing information and interpreting observations. Structures exist in many layers of hierarchies. Within any structure there may be substructures. The concepts of structure used to organize systems are: the closed boundary; feedback loops; levels and rates; and within a rate, the goal, apparent condition, discrepancy and action. These concepts of
structure organize into the following hierarchy of major and subordinate components:

I. The closed system generating behavior that is created within a boundary and not dependent on outside inputs.
   A. The feedback loop as the basic element from which systems are assembled.
      1. Levels as one fundamental variable type within a feedback loop.
      2. Rates or policies as the other fundamental variable type within a feedback loop.
         a. The goals as one component of a rate.
         b. The apparent condition against which the goal is compared.
         c. The discrepancy between goal and apparent condition.
         d. The action resulting from the discrepancy.

We are interested in systems as the "cause" of dynamic behavior. The focus is on interactions within the system that produce growth, fluctuations, and change. Any specified behavior must be produced by a combination of interacting components. These components lie within a boundary that defines and encloses a system. Formulating a model of a system starts with defining the boundary, that encompass the smallest number of components, within which the dynamic behavior under study is generated. The boundary must not be violated except for exciting the system for observing its reactions.

Within the boundary, the basic building block is the feedback loop. This is a path coupling decision, action, level or condition of the system, and information, with the path returning to the decision point. The decision process implies a far broader concept than merely human decision-making. Decision can be any mechanism, that is based on available information, that controls an action that influences a system level; that generates new information that modifies the decision stream.

At a lower level each feedback loop contains a
There are two fundamental types of variable elements within each loop; the level and the rate. Both are necessary. The two are sufficient. The level or state variables describe the condition of the system at any particular time. The level variables accumulate the results of action within the system. They can be represented by level equations. Computing a new value of a level variable involves the previous value of the level variable itself, the rates or actions that cause the level to change, and the length of time since the last computation of the level. The level variables accumulate the flows described by the rate variables. The rate variables tell how fast the level variables are changing, it is not instantaneously measurable. Rates depend only on levels and constants. Level variables and rate variables must alternate. Levels completely describe system condition.

Four concepts are to be found in a rate equation, that is a policy statement: (i) a goal, (ii) an observed condition of the system, (iii) a way to express the discrepancy between the goal and the observed condition, and (iv) a statement on how action is to be based on the discrepancy.
2.2 DYNAMIC PROCESSES

DECISION MAKING

Broadbent (1973) states that as a first approximation, an architect must be capable of thinking in the following ways:

1. Rational thinking (about the nature of the site, the available resources and so on).
2. Intuitive or creative thinking (about what these results of rational thinking imply for the building form).
3. Value judgements (as to what the relative importance of these various and times conflicting factors).
4. Spatial ability (the ability to visualize and represent the decision), and
5. Communication skills (in order to make their design intentions known to other people).

It soon becomes evident that a predicting system and a value system strongly determine the outcome of any of the above attributes. The decision-maker after Bross (1953) shown in Figure 2.2.1 is a convenient representation. After the data is collected, it is fed into the 'Predicting system' from which one obtains a list of possible outcomes for each action, and the 'probability' (certainty, risk or uncertainty) for each one. The data is also fed into the 'Value system' from which one obtains a second quality; the 'desirability' of each outcome. Value is normally measurable in terms of cost-benefit, cost-utility, or cost-desirability, all input-output ratios, on progressively more subjective scales. At this point the decision-maker has to make a recommendation based on the decision criteria, that now include:

1. A list of outcomes for each action.
2. A probability associated with each outcome.
3. A desirability associated with each outcome.
THE VALUE SYSTEM

The value analysis process may be divided into six stages:
1. Preparation phase (stating the problem);
2. Information phase (getting the relevant facts, data);
3. Evaluation phase (definition of the function required);
4. Creative phase (generate alternatives, reducing costs);
5. Selection phase (scan alternatives, recommend choice);
6. Implementation phase.

Hall (1962) points out that in specifying the physical performance of a system, we inevitably use terms such as inputs, transformations, outputs, boundary conditions and so on, but all the time we are really concerned with the physical performance of the system. This in fact implies setting up a value system, that may have some, or all, of the following criteria:
1. "Profit" which, is the motive for most industrial production. Actual profit requirements for any specific product can be specified very closely. The 'market' and the 'cost' determine the economic feasibility of a product whereas 'capital and running costs' are important to both manufacturer and consumer.
2. "Quality" may be measured in many ways. During manufacturing it can be measured objectively, but once a product is in use it may be valued entirely subjectively. Physical design may be based on psychological tests, even though consumer reaction will eventually be subjective.
3. "Performance" objectives may be of this kind, but they
also cover such criteria as 'system reliability', which may be expressed in terms of the probability that the system will operate in the environment for which it is designed for longer than the minimum specified period.

4. "Competition" may be an important spur in defining the objectives of a system, for any context.

5. "Compatibility" with existing systems may also be very important, especially where large amounts of capital are to be, or have already been invested.

6. "Flexibility" refers to the ease with which a system may be adjusted or modified to take account of expansion or changing use. It may or may not conflict with 'performance' which in itself is difficult to measure, especially for unpredictable technical advances.

7. "Elegance" is often seen, by engineers, as a function of simplicity which in itself is very subjective.

8. "Safety" is also difficult to measure, and must be set against the actuarial values which insurance companies put up for the specific losses.

9. "Time" is one of the most important criteria of all, especially in competitive situations. It interacts with profit, cost variables, the state of the market and so on. 'Quality' is a function of design and development time, so is 'flexibility', and maybe even 'elegance'.

Hall's list, begins to indicate the complexity of a value system initially derived from an objective definition of the physical performance of a system.

THE PREDICTING SYSTEM

Bross (1953) outlines a series of prediction techniques, for finding the various outcomes for each variable. They are:

1. "Persistent prediction" is based on the fact that for certain practical purposes circumstances do not change. Once the consistencies or invariants are known, there is no reason to suppose that they will change. However, in certain circumstances, persistance is useless, such as under
conditions of rapid change.
2. "Trajectory prediction" is a matter of observing trends, particularly in the short-term, and predicting possible consecutive trends. There are obvious difficulties in long-term forecasting on this basis.
3. "Cyclic prediction" depends on the lessons of history. Yearly seasonal changes are determined on this basis. To be effective, it however needs a great deal of data going back, over several cycles, unlike 'persistent prediction' which merely needs the latest case, or even 'trajectory prediction' which can be undertaken on the basis of three cases.
4. "Associative prediction" is a matter of observing relations between two or more events. These include the various types of cause-effect relations and the type and characteristics of the relationships. Associative predictions can become very complex as the number of characteristics to be taken into account increases.
5. "Analogue prediction" is perhaps the most potent of all, because it can take so many forms. It is based on the inherent properties of analogy, that two things which have certain properties in common are assumed to be alike for properties about which knowledge is limited to one of them.
6. "Hindsight prediction" is certainly the most effective, but perhaps the least understood of all forecasting devices. It is the prediction of an event 'after' it has occurred, and is often used in technological forecasting. The important factor being one of knowing or identifying already existing knowledge.

MODELS

As models are either used for prediction or simulation, they have one or the other of the above characteristics. In Operations Research literature models are classified as "descriptive" or "normative". The former being either 'static' or 'dynamic', and the later being of the 'analog' type. But this classification is unnecessarily restrictive,
as 'iconic' and 'symbolic' models are often used, especially by architects. However when one considers them from the point of view of manipulation rather than only representation, the OR classification seems sufficient. As the present concern is with processes, and as processes are time dependent, the main focus will be on dynamic models. Analog models will be used when comparing normatives at specific instances to demonstrate mutations.

**REPRESENTING RELATIONS**

The problem of representing relations is closely related to the representing of knowledge itself. The issue is not one of enumerating the types of possible static relations between the elements of a set, such as reflexive, symmetric, transitive, connected or their converses and deviations, but one of ordering the elements in terms of dynamic forms of relations. Dynamic representations require certain operators such as addition and subtraction, multiplication and division, or inclusion and exclusion.

As nouns represent things, and verbs represent actions, static and dynamic relations could be abstracted from their respective characteristics. Investigation show that nouns are structured in hierarchical fashion and organized in trees. Verbs on the other hand form networks of functional relations that can operate on different levels of the hierarchical noun structures. The trees and lattices representation in language, can be compared to the sections and plans of buildings.

In the "hierarchical tree structures" of nouns, the bonds depend on the type of static relations and their strengths. In the "latticed functional levels" of verbs, the bonds depend on the number and type of active relations and their relative strengths.

As structures represent "a thing in itself", they are 'prescriptive' and closed systems. Functional representations are 'descriptive', "its relation to others", and hence are open systems.
Fig. 2.2.2
Ascending hierarchical definition structure for nouns. Structural relations are organized in trees.

Fig. 2.2.3
Closed heterarchical definition structures for verbs. Functional relations form latticed organizations.

Fig. 2.2.4
Cognitive profile elicited by the implication grid method. The method requires that the subject states whether or not changes along one construct dimension imply an effect on any other construct in the system. In the graph constructs (nodes) are ordered vertically according to the number of links (arcs) implied by other constructs. The greater the number of implications, the more important the construct, and, the more resistant to change.
Prescription is solving by representation, and hence is analytic. Whereas description is representing by solving, and hence is synthetic.

In representing relations function follows structure hierarchically, and hence depends on our point of view. In solving problems function and structure iterate.

Successfull representation at one stage in the hierarchy may uncover a new problem, that is solved through several levels of iteration till a successfull representation is possible again. If the representation itself is a dynamic model, it can be considered a new problem to be solved.

In architecture the potential of such representations of a descriptive kind are made use of in performance specifications, and can be viewed as passing-the-buck; the problem to more competent solvers or expert domains where the prediction and value systems are more reliable.

**STEPS IN PROBLEM SOLVING**

Most views on systems building in architecture, are adopted from the systems sciences. Models of decision making, such as those of Churchman (1957) and Sargeaunt (1965) are characterized by a certain sequence of steps or phases used for problem representation and solving. These are:

1. "To understand the problem".
   Recognizing the occurance of difficulty. Stating the problem involved. Formulating objectives and goals.

2. "To gather information".
   Collecting relevant data. Constructing a model. The 'creative leap' or synthesis occurs heare.

3. "To analyse the information".
   Analyzing the data. Deriving a solution to the model.

4. "To generate solutions".
   Manipulating and testing the validity of the model and the solution derived from it under varying circumstances.

5. "To assess the solutions".
Establishing controls over the solution. Selecting an optimal course of action.
6. "To implement".
Putting the solution to work: implementation.
7. "To test".
Continuous check on the validity of the model in the light of fresh data.
8. "To modify".
Adjusting or modifying the model or the solution.
Various authors give different names to these steps.

Often consecutive steps may be overlapped, or even represented together. Operations Research is closely related with a particular type of systems approach which proceeds as follows:
1. "Define the solution space", this being a manifold of solutions, a set of variables, a combination of which make up the set of consieved of solutions.
2. "Define the constraints", i.e. describe which of these solutions have to be excluded because they are not feasible.

3. "Define the measure of effectiveness".
4. "Optimize the measure of effectiveness", i.e. identify or search for the solution in the solution space which is within the boundaries of the constraints and for which the measure of effectiveness assumes a maximum value. Usually it has to be demonstrated, that within the set of feasible solution there is no better solution than the one for which optimality is claimed.

These steps of OR can be applied to or substituted for the later steps of the general systems approach described above.

PLANNING AND DESIGN PROCESSES
Morris Asimow (1962) describes design almost entirely in terms of information processing. It consists, he says, of "the gathering, handling and creative organization of information relevant to the problem situation; it prescribes
the derivation of decisions which are optimized, 
communicated and tested or otherwise evaluated; it has an 
iterative character, for often, in the doing, new 
information becomes available or new insights are gained 
which require the repetition of earlier operations".

His method clearly derives from systems engineering, and 
his strategy, the 'planning process' or 'design morphology', 
has two scales of operation comprising of the following 
stages:
1. feasibility study.
2. preliminary design.
3. detailed design.
4. planning for production process.
5. planning for distribution.
6. planning for consumption.
7. planning for retirement of the product.
The detailed designing phase is further subdevided:
1. preparation for design.
2. overall design of subsystems.
3. overall design of components.
4. detailed design of parts.
5. preparation of assembly drawings.
6. experimental construction.
7. product test program.
8. analysis and prediction.
9. redesign.
Finally he outlines a general process for problem 
solving which he calls the 'design process', and which has 
the following stages:
1. analysis.
2. synthesis.
3. evaluation and decision — which is extended into 
4. optimization (analysis).
5. revision (synthesis).
6. implementation (evaluation).
Asimow sees his 'design morphology' or 'planning 
process' as the vertical structure of engineering
problem-solving and his 'design process' as its horizontal structure. Each step in his morphology contains the sequence of events which he describes as the 'design process'.

As several views underlying the 'design process' have already been discussed, the arguments supporting the analysis-synthesis-evaluation sequence will not be repeated here. Search techniques relevant to problem solving will be discussed later on. The 'design morphology' or 'planning process' elaborated above have both sequential and at times hierarchical relations. Hierarchical relations are not necessarily sequential in the planning process, but have to be structured sequentially in actual implementation.

Planning decisions may involve either prescriptive or descriptive specifications. If prescriptive specifications are adopted at a particular level, they will sooner or later be translated into descriptive specifications. At any level in the hierarchy of the decision sequence prescription and description follow each other. Prescription specifies the parameters of the problem to be solved, whereas description is a statement on, or state of the solved or partly solved problem.

Thus in problem solving the iterative analysis-synthesis-evaluation design process interacts with the iterative prescriptive-descriptive planning process. We shall see later on how the theory of dynamic systems can be applied to these processes.

INFORMATION PROCESSING

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<thead>
<tr>
<th>PLANNING PROCESS</th>
<th>DESIGN PROCESS</th>
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<tbody>
<tr>
<td>(Description-Prescription)</td>
<td>(Analysis-Synthesis-Evaluation)</td>
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<tr>
<td>(Relations well defined)</td>
<td>(Relations ill defined)</td>
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<tr>
<td>(Certain)</td>
<td>(Uncertain, risky)</td>
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<tr>
<th>DECISION MAKING</th>
<th>PROBLEM SOLVING</th>
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<th>IMPLEMENTATION TECHNIQUES</th>
<th>SEARCH TECHNIQUES</th>
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Fig. 2.2.5
The differentiation of information processing in design and planning processes.
2.3 SYSTEMS BUILDING

THE SYSTEMS APPROACH

The "systems approach" is the process in which a problem is viewed as a set of interrelated parts which "work together for the overall objective of the whole" (Churchman 1968). The systems approach is necessary though not sufficient for the successful discovery of a solution to every problem.

A "building system" is a set of interrelated, interdependent or coacting parts with an information base, that defines the relationships between the parts, and determines how they are assembled and work together, taken apart or substituted, to accommodate the varying needs and objectives of a building program.

"Building systems may or may not be created by the systems approach, and the result of a systems approach may or may not be a building system" (Ehrenkrantz 1970).

"The systems approach, when applied to building problems, results in a process whereby resources and needs can be related effectively to performance, cost and time. There are five basic resources which one deals with in building: land, finance, management, technology and labor. Needs, or user requirements, may relate to standards of space, services, etc." (Ehrenkrantz 1970). The process of planning and design is essentially the matching of resources with needs against constraints, to fulfill the criteria for a satisfactory solution.
Fig. 2.3.1
Operations for generating satisficing solutions.

STEPS IN GENERATING A SYSTEM

The systems approach, as developed by Ehrenkrantz, for resolving building problems, has a number of general steps. These are ordered and detailed on implementation depending on the nature of the problem. The steps are:

1. Statement of objectives.
2. Problem analysis and base line data gathering: analysis of (i) the state of the art to benefit from relevant work done in the past and to form a basis for meaningful and organized progress; (ii) all parts of the problem and the relationship(s) between the parts; (iii) the variables and constraints which will affect attainment of the objectives, i.e. labor unions and building codes, etc.; and (iv) identification of the needs of the potential uses of the building through surveys, interviews, etc.
3. Development of performance criteria (stating what an item or a space must 'do' not what it must 'be') based on identified user needs.
5. Evaluation and selection of alternatives based on previously defined performance criteria, or through bidding (and, in some cases, by the use of quantitative models which simulate and predict the performance of alternatives).
With the exception of the very last step in the approach, the rest of the process may be quite conventional: detailed development of the selected alternatives with subsequent fabrication and assembly of the building(s).

After construction is completed, the last and perhaps the most important step in the process occurs: evaluation of the actual performance of the selected alternative in comparison with previously determined performance criteria. This makes it possible to modify the solution and improve it before it is being implemented again, and it provides a basis for meaningful progress and further improvement in future work.

The systems approach has a number of advantages when compared with the conventional design process: (i) It permits completeness of problem definition; (ii) it results in an earlier and more reliable prediction of the eventual cost and user acceptance of the product; (iii) it enables one to utilize the concepts of performance more effectively; and (iv) it provides a means by which one can continually evaluate solutions generated against rationally defined objectives and criteria through the design process.

CONTROLS FOR OPTIMIZATION AND ALLOCATION

One could argue that the approach of balancing needs and resources is a traditional one. But this is only approximately true, as in actual practice, the conventional design process is far from systemic. First, there is no 'control over the program or budget and hence the design or resource optimization process', requiring unnecessary redefinition and reworking at every stage. Secondly, the present complexities of 'resource allocation call for controls that require more predictable and effective procedures'.

If, instead of beginning to compromise after the design has started, one were to first develop a feasibility study based on cost data, gross compromises could be made in the program before design began. Such an initial investigation
would develop information for testing whether the program could be handled within the means of the available budget. Once this is done the design process could begin.

The development of controls for optimization and allocation is part of the systems approach. The development of information based on past construction performance and cost, along with a definition of the needs of prospective users is the prerequisite. This base is used, through the controls, to develop building programs which specify performance criteria and cost targets that serve as guides for the design process and criteria for evaluating the results of the design process.

In order to meet current-day building requirements, the cost targets in such a program must be subdivided and related to the many separate parts or subsystems of the building such as structure, floors and roofs, interior and exterior partitions, all of the services, casework and built-ins, etc. It requires that one deals with these costs in terms of functional parts of the building and not in terms of building trades. Building trade cost and content is only important for progress payment to specific contractors. Hence, one really requires a two-way estimating method to obtain 'controls' of resources for progress payments and to obtain 'information' for the selection of materials as an integral part of the design process.

The systems approach requires that needs be related to resources until a balance is determined so that one can begin to design in the traditional manner, going from schematics through working drawing without trying to alter the budget at the same time. If, however, the user requirements are such that a set of appropriate needs cannot be answered with available resources, one must look at the total context within which the job is to be done to see if there is a way of altering the procedures, the way in which any of the resources are supplied, or the resources themselves in order to have the opportunity to develop acceptable solutions.
MEETING REQUIREMENTS THROUGH INNOVATION

The School Construction System Development Project provides one example as just described. Here, it was not possible to meet basic educational requirements within a California state aid budget for more sophisticated schools. Airconditioning, flexibility for educational evolution within the school over time and a physical quality necessary for a viable educational environment could not be supplied within the context of single building projects designed and constructed one at a time.

In this case the architects and the educators had to look at the basic resources and seek appropriate changes which would make it possible to meet the requirements. A new management device was then developed which tied 13 school districts together into a single bidding entity. Their needs were expressed in performance terms and bids were taken from a large number of industrial firms in order to obtain prices for new products and technologies which could be developed to meet the specific educational requirements within the allocated budget. In this process, there was concern with the acceptability of these new products and technologies and their incorporation within the building without problems caused by jurisdictional disputes on the part of the building trades. Finance and labor in this case were taken as given and the development — through a system approach — of a particular building system was brought about, using quite highly developed industrialized components.

The establishment of a volume market as a management device to bring new products into being was used basically for the purpose of innovation. These products have since been used in a considerable number of schools designed as single projects and in many other building types as well. Products developed as part of this process set new standards within the industry, and once set, many other firms provided products of equal performance and cost.

But, a large volume of construction and a predictable
market is not necessarily required for a systems approach to building. It may be required only if, within the context of a systems approach, one desires radical changes from existing techniques and finds a need to create sufficient incentive in order to bring these changes into being.

RULES AND INTERFACES

The final product or hardware of SCSD, was a building system. The basic software portion of the system, or its rules and information base, is essential for designing projects within the contexts of cost, time and performance in a reliably predictable manner. Each subsystem such as structure, HVAC or partitions within a building system must be represented by a number of equal performance alternatives that are interchangable. The rules for the 'interface' of these subsystems and their alternatives must be understood for the group of components to be thought of as a building system. In other words interface relations determine compatability.

The selection of the optimum combination of alternative subsystems for a building system in terms of cost and performance must be done through controlled bidding procedures, as on the SCSD project, or it may be facilitated by using the optimization techniques of linear and/or dynamic programming. The cost flexibility and efficiency implecations of alternate configurations of the building elements of a particular building can thus be worked out using a computer program.

OPEN AND CLOSED BUILDING SYSTEMS

Building systems may be classified as closed or open. In closed building systems the juxtaposition of the basic subsystems has been predetermined in a specific way so that, for example, particular air conditioning or lighting or partition products must be used with a specific set of structural components. There may be certain options in other component areas, but a significant proportion of the
building uses specific products for the better part of the subsystems.

Open building systems offer more freedom. A variety of different subsystems may be used together with a high level of interchangeability, due to the compatibility created by specified interface requirements. Such building system can remain viable over long period of time, for as a subsystem becomes obsolete, a new one which performs better can be phased in with the remaining subsystems so that the total building system remains cost effective. Upgrading and continual improvement of performance over time is thus also possible. Large volume may stimulate specific levels of upgrading, or new manufacturers entering the market can compete with and improve upon existing products. Open systems, therefore provide an opportunity for evolution and improvement not known in closed system.

Closed building systems, however, may permit single companies or a cluster of manufacturers to gain tighter control of their products and may in some cases provide a more highly organized total delivery system for the construction of specific buildings. If simplicity, speed and efficiency in construction are the determinants, then there may at times be a case for closed systems.

THE ADVANTAGES OF INDUSTRIALIZATION

A systems approach to building does not necessarily require the use of industrialized building systems or prefabrication. Work for any project may be done in a factory or at the building; this is not predetermined. Building systems may, of course, provide the best way to obtain a desirable solution in terms of cost, time and performance in a specific job. Modern manufacturing capabilities permit us to look favourably towards industrialization for the development of more effective subsystems for buildings, than in the past. A systems approach, however, may readily be used for putting conventional products together in a traditional manner.
The factors which impel our more favorable attitude towards industrialized products include those which are related to increased building costs, inadequate production capabilities, poor technical performance and prolonged construction time. However, these factors may be addressed systematically, for example by a "fast-track" approach to scheduling of the entire building process from programming through occupancy, for either conventional construction or for industrialized building systems.

There is also a frequent shortage of available people with appropriate skills within the building trades. The difference in wage rates between the factory and the craft unions on the building site provides considerable impetus to take advantage through industrialization of lower wage rates, higher production rates and perhaps more effective production. The increasing cost and complexity of all the service elements which must be combined within a given project also call for a level of coordination and predetermination of how these products may fit together that moves one towards the use of better produced components with greater quality control. These and other factors are swaying the balance over time in favor of industrialized building systems and products as opposed to conventional building strategies. A systems approach, however, does not require the use of such products on any given job.

THE NEED FOR INFORMATION

One can see that a system approach can take place either with conventional products or newly developed ones. It will become easier to take a systems approach, however, as more and more building systems are developed with known performance for specific groups of products working together. However, adequate information developed by architects, engineers, cost consultants, etc., makes it possible to do appropriate system design without specific building systems. In effect, such information in many instances permits the development of a building system out
of conventional products. In some cases, architects practicing in a relatively traditional manner develop such building systems and take a systematic approach to implement them.

The need is increasing, however, for greater order and better information concerning building elements primarily due to the greatly increased number of improved products, capabilities and requirements which must be built into our projects. This constantly growing dimension of complexity calls for greater care in developing procedures for integrating this information into our work.

It is not for us to determine, however, what a building system should be or how to value one approach with respect to another. An architect must take a look at the basic requirements of the client and choose which building system or nonsystem is appropriate to get the best use for the money. For these reasons, the further development of the systems approach to buildings must be encouraged within the professions, and appropriate information packages about the products must be developed, so that field costs and performance of these products can be more readily predicted.

We should pick opportunities to support development projects to bring new products and procedures into use which will give us a better chance of meeting our clients' requirements. We must realize that this will bring change with respect to government agencies, management procedures, the roles of those involved within the building process as well as the technologies themselves. If we are to maintain a position of leadership in the determination of our physical environment, we must take a major role in advocating the changes which will result in improvement of the environment.
Fig. 2.3.2
Developing the hardware of a Building System.
Guidelines prepared by the Editors of Industrialization Forum.

FORM THE SYSTEM DEVELOPMENT TEAM

ANALYZE THE BUILDING TYPES WITHIN THE MARKET

CHECK-OUT THE POTENTIAL MARKET

COMMENCE SYSTEM DESIGN

ANALYZE AND EVALUATE EXISTING SYSTEMS

MAKE A FORMAL CHECK OF THE SYSTEM DESIGN

RECYCLE

START PRODUCTION

MAKE MAJOR MANAGEMENT DECISIONS

START FIELD TESTS
2.4 SYSTEMS PERFORMANCE

The performance concept is the link mechanism between the doing and the using. It also spurs improvements.

THE PERFORMANCE APPROACH

The performance approach is a systematic procedure for precisely stating the desired attributes of a product or system's performance without regards to the specific means to be employed in achieving the results.

Performance specifications are written in terms of 'descriptive' functional requirements rather than in 'prescriptive' design or construction requirements.

Performance specifications have three essential components:

1. "Performance Requirements". The requirement is a qualitative statement about the important aspects of product quality. It answers such questions such as what? for whom? why? when? where?

2. "Performance Criteria". The criterion is a quantitative statement providing specific minimum levels for attaining compliance with the intent of the requirements. It includes both primary and secondary imperatives and desirable costs.

3. "Performance Evaluation Techniques". The evaluation technique or test portion of the performance specifications indicates the specific method of evaluation or assessment. These may include physical tests, simulations, and panels of experts.

The performance approach forms levels of concepts as shown in Figure 2.4.1.
CONCEPTS

The creation of performance requirements and criteria are useful as a way of organizing thought, i.e., of making explicit otherwise implicit goals. In this respect the performance approach is similar to formal cost benefit analysis and other systemic methods of attacking problems.

The performance approach makes it easier to spot questionable requirements in a standard. Unlike traditional prescriptive standards they also encourage competition and innovation. With time even performance standards need to be updated, as changes in user requirements, improvements in technology or testing methods demand revision.

Performance standards complement design standards. Good performance standards often include prescriptive specifications of current state-of-the-art methods that meet the performance criteria. They serve the dual purpose of informing how to meet the specifications for particular applications as well as in manufacturing.

Conversely, performance standards are implicit in any
prescriptive specification. Often a first step in writing performance standards is to state these criteria explicitly, later testing will determine whether they are set at correct levels or not.

Building codes and traditional prescriptive specifications often include "equivalency" statements. Products which pass the implicit performance criteria embedded in the prescriptive specifications should be acceptable theoretically. But this is still remote from the performance approach, as the burden of proof is placed on the innovator.

![Diagram of Range of Building Problems]

Fig. 2.4.2
The range of applicability of systems concepts and performance concepts to building problems.

CHARACTERISTICS

The performance approach has definite advantages. But certain characteristics must be recognized:
1. Poor performance standards are possible, where they emphasize relatively unimportant criteria and neglect important functional characteristics. Thus placing better products at a disadvantage.
2. Performance standards will be restrictive, and in practice a hierarchy based on their restrictiveness will be necessary. The performance approach tries to create criteria and test methods for requirements as high as possible on the hierarchy. In practice however, criteria and tests may be
simpler, cheaper and make more sense if the focus is narrower and more restrictive.

3. Cost and quality decisions are still required, as it is theoretically not possible to define the attributes necessary to satisfy human needs. Preferences and affordability problems prevent the unique.

4. Quality trade-off decisions are still necessary, especially when a product has two or more attributes. Trade-offs may be difficult to write, monitor or enforce. But they may be quite useful and efficient. Permitting all beneficial trade-offs, requires beginning at the very highest level of the performance hierarchy.

**Fig. 2.4.3**

Hierarchy of performance specifications based on restrictiveness. Several such hierarchies based on different requirements and criteria for the same ultimate function are related horizontally in the final performance specifications. An analogy with Chomsky's (1965) theory on the structure of language springs to mind.

**ADVANTAGES**

There are five important reasons for the development and application of performance specifications in the building industry:

1. The voice of the user: Satisfying the needs of the users is difficult in today's complex and fragmented building process. Performance specifications guarantee that the valuable information based on users' needs, is translated
into performance requirements and criteria are thus not lost in the procurement process.

2. Information-rich procedures: Because the use of performance specifications relegates the responsibility for design decisions to points further down in the decision process, closer to the products origin, it permits these design decisions to be made when more information is available to the designer.

3. Spur to innovation: By avoiding prescriptive specifications of what a solution must be, and rather describing what performance any solution must yield, paves the way to innovation. By permitting any solution which meets the performance required, the building industry is permitted to explore alternative solutions to those now seen as models.

4. Increased cost-effectiveness: By permitting innovation, performance procedures can result in innovations which reduce first costs and/or life costs. Performance information makes it possible for industry to bring the cost of their products within the demand capability of the market by focussing on the basic performance characteristics of the products, rather than less important information.

5. Formal evaluation and feedback: By stating the desired performance explicitly in terms of criteria and test methods, one is able to have a precise brief or program against which evaluation may take place. Since all design assumptions are in the form of requests, criteria and test methods one is able to evaluate the correctness of these assumptions. This forms the necessary information base for a system of formal evaluation and feedback, both sorely needed in the building industry.

IMPLEMENTATION PROBLEMS
Performance standards are preferable to prescriptive standards. But prescriptive standards still dominate for the following reasons:

1. Difficulty in writing standards and creating test
methods. The problems of creating subjectively valid and objectively acceptable tests are not easily surmounted, and the costs involved are often prohibitive. The problems of decentralized decision-making is that individuals may not have enough incentives or motives to become involved in the time-consuming process of creating standards.

2. Evaluation problems of judging new technology by rapid, inexpensive and fair judgement. This problem could be solved by direct government action like in the French Agre’ment System; or better still in the form of promoting independent, and reliable evaluation systems for new and innovative products.

3. Problems of administration and enforcement. Physical specifications are easier to enforce and inspect, as they necessitate less skills and training. The problems of liability responsibilities is another disincentive. On the other hand design standards are often more difficult to enforce than general performance specifications in hazardous conditions.

INAPPROPRIATE USAGES

There are certain areas where performance standards may not be prefered to design standards.

1. Testing standards, as they are always written in prescriptive terms. The need to assure compatibility seems to outweigh the possible benefits for encouraging innovation through the use of performance standards for test methods.

2. Safety standards. It is often impossible to ensure that innovative items meeting performance criteria are as reliable as well known and often-used products which pass the same test.

3. Interconnection Standards. Here again the main reason for preferring prescriptive standards over performance criteria is that they are known to work. But performance criteria can specify interconnections as key requirements without prescribing how interconnections are to be achieved, thereby allowing innovation. It is true, however that where
performance tests are suspect, it is often better to use design specifications.

LEVELS OF APPLICATION

Brill (1972) believes that there are four levels of application of performance specifications: hardware, environmental characteristics, activities and objectives. Of which only the first two are presently used.

1. Performance Specifications for Hardware Solutions are not normally user-based, but based on the capabilities of manufacturers to produce hardware of specific characteristics. Product standards are set for an industry to specify standards of performance and also size, joinery, shape, finish and other prescriptive criteria. These standards when codified lead to a dead-end in terms of innovation, because the model of performance is not some need but some existing solution.

2. Performance Specifications for Environmental Characteristics are normally based on (i) the environmental characteristics needed by the users, and (ii) have so far all been organized around building subsystems. (iii) The environmental characteristics are mapped against the building subsystem in a matrix. (iv) Information is developed for each intercept in the matrix which describes the response which each subsystem must have to the desired environmental characteristic. Each intercept containing the requirements, criteria, and test. (v) The performance information is developed for each subsystem (vi) and organized as a procurement document, which also contains information to bidders, bidding and pricing information, general conditions for system development and construction requirements, and performance specifications for the total system.

Such performance specifications have certain drawbacks. First, the use of building subsystems as the method of organizing specifications precludes some basic innovations. Secondly they seldom deal with man's sociological and
psychological requirements, and last of all, they are not organized by activities and hence don't handle environmental constraints.

3. Performance Specifications for Activities could solve some of the above mentioned problems that originate with subsystems. Performance specification modules could be developed for each activity, which could be appropriately organized for a project. Design-build contracts could benefit from this, but the hardware oriented building industry would have to undergo some fundamental changes to be able to respond effectively.

4. Performance Specifications for Objectives could be organized into an information processing and decision support system. Such a system would be very effective in procuring buildings with the best overall performance using existing products, but it may be too remote to add incentives for innovation within the industry. As such performance specifications are highest in the hierarchy, they obviously are the least understood, but have the best potential for further development.
Fig. 2.4.4
Flow diagram of general evaluative procedure.
2.5 BUILDING DYNAMICS

CHARACTERISTICS OF THE SYSTEMS DESIGNER

As the systems designer influences the rules and representations that determine the interfaces of the system, which in turn determines the systems performance, he deserves closer scrutiny.

1. The designers attitude should be somewhat 'detached' from the problem at hand: he should try to be rational, objective and scientific in attacking his problem.

2. He is characterized by the attempt to 'grasp the whole of the system' rather than someone who undertakes piecemeal improvements.

3. And because the whole system has many facets and the problems are not the responsibility of any single discipline, the approach of the systems analyst or designer must necessarily be 'interdisciplinary'. Some systems designers prefer to call themselves generalists in contrast to the specialists of a single field.

4. Another characteristic is that he is trying to 'optimize', i.e. to incorporate all relevant and important aspects of the problem at hand into one effective measure which he tries to maximize. He deals with economics in the broad sense, not in the narrow monetary or budgetary sense; he is trying to maximize productivity in the sense of optimizing resource allocations.

5. The systems analyst is supposed to be 'innovative', i.e. to develop novel solutions from the formulation of the problem, or, as it is called, from the mission of the project.

RULES AND REPRESENTATIONS

Now, how does the systems designer fulfill these personal objectives? He requires rules and their representations to act and convey his thoughts. And for this he has to develop an effective interface.

Rules and their representations determine the behavior
at the interface between any two systems. Rules can be implicit or explicit. Implicit rules do not require elaboration if they are understood, or alternately, if they are systems state properties of the adaptive self-stabilization sort. Explicit rules are required, not so much as to clear ambiguities, but to reduce the number of options available for action. The degree of freedom, or qualitative diversity admissible at the interfaces, is inversely related to the quantitative abundance of interacting elements involved. Thus rules or representations must be kept to the minimum and be as simple as possible. On the other hand structural stability as a result of explicit but rigid rules is undesirable, as it is related inversely to self-stabilizing functions. Therefore the aim of the systems designer should be to have a few explicit rules with flexible structures.

CHARACTERISTICS OF THE DESIGNED SYSTEM

Interfaces exist among and between man, the building system, and the environment. The rules and representations must reflect these relations dynamically, that is, over time. They fall under the following categories:

1. Relations and preferences, for determining desirable interfaces. This involves planning and design of the system, including organizational design, the preparation of performance specifications, and the process for the realization of the building system. This requires systems performance and building performance documents.

2. Actions and their consequences, for constructing interfaces and evaluating them. This involves the actual realization of the system, and its testing. This requires construction documents.

3. Utility in use, for determining how interfaces will stand up to everyday use, changes, expansions or modifications. This involves monitoring of the systems performance and the total environments performance in use. This requires users manuals and performance evaluation guides.
4. Utility over time, for interfaces that facilitate removal, replacement or renewal. This concerns mainly the long term performance evaluation and maintenance of the building system, and requires continuous monitoring. This requires maintenance manuals and procedures.

5. Control of interfaces. Though the four different sets of rules and representations are designed for specific purposes and time periods, that overlap in the first two and coincide in the others, their potential influence on each other is of prime importance. So, in true system fashion they should be designed simultaneously, and will therefore require a set of second order rules and representations that would control higher level interfaces.

As all the rules and representations would represent desired states of the total system over specified time periods, and as they would all require some performance measure, monitored by the controlling interface, every aspect could be dynamically monitored and adjusted if required. An information monitoring and processing system will be considered in the section on ‘Supports’.
2.6 DYNAMIC SHIFTS

SHORTCOMINGS OF THE SYSTEMS APPROACH

Rittel (1972) presents four paradoxes of rationality in systems thinking. He states if "Rational behavior means trying to anticipate the consequence of contemplated action", then:

1. One would endlessly try to anticipate the consequences of consequences of contemplated actions. Because of the possibility of such endless tracings, he concludes, therefore, "there is no way to start being rational", as one could always start a step earlier.

2. As an attempt to be rational, leads to the insight that every consequence has consequences, there is no reason to stop tracing consequences, other than extra-logical or extra-rational reasons. Hence, "rationality once started cannot be stopped again".

3. The further one constructs causal chains into the future the more uncertain one becomes as to which terminals will eventually become the case, as a consequence of a particular course of action. This means that, "the better one succeeds in being rational, the more it incapacitates one" in the long run.

4. Self-containment demands that to study the consequences of a course of action one requires a model. As the model itself influences consequences, it must be part of a model, or in other word, "the rational model must contain itself, which is impossible".

These he claims are the most serious objections to the systems approach of the first generation. Most research on creativity and problem-solving is about "determinate" or "tame problems", because they are easy to manipulate and control. But "indeterminate" or "wicked problems", such as those of planning, are not well understood, since they cannot be simulated. Rittel contrasts the properties of wicked and tame problems.

1. The tame problem can be exhaustively formulated, and
requires no additional information for its solution. In order to give exhaustive information ahead of time for a wicked problem one would have to anticipate all potential solutions before one can solve it. “Wicked problems have no definitive formulation”.

2. “Every formulation of the wicked problem corresponds to a statement of the solution” and vice versa. This is very different from the tame problem, where one thing is the problem and another the solution.

3. “There is no stopping rule for the wicked problem”, as one can always do better, unless one runs out of time, money or patience. Tame problems have definite endings.

4. Solutions to tame problems can be tested and assigned either of two attributes, correct or false, and mistakes or errors can be pinpointed. “Wicked problems can only have good or bad solutions. Correct or false is not applicable to relative solutions”.

5. For tame problems there is an exhaustive list of permissible operations. “For wicked problems there is no exhaustive, enumerable list of permissible operations”; everything goes as a matter of principle or fantasy.

6. The trouble is that “in wicked problems there are many explanations for the same discrepancy” and there is no test for deriving the best explanation. The direction in which the solution goes thus depends on the first decisive step of explanation.

7. Every tame problem has a certain natural form, and there is no reason to argue about, for example, the level of the problem. But “every wicked problem can be considered as a symptom of another problem”.

8. Solutions to tame problems can be tested. But, “for a wicked problem there is neither an immediate nor an ultimate test”.

9. Tame problems can be solved repeatedly. “The solution to a wicked problem is a one-shot operation”.

10. The tame problem solver may win or lose without being blamed for it, or may state a hypothesis which will be
refuted by someone else. But, "the wicked problem solver has no right to be wrong". He is responsible for what he is doing.

THE SYSTEMS APPROACH OF THE SECOND GENERATION

As many of our problems are indeterminate or wicked, the systems approach as formulated in the first generation is ineffective. Rittel enumerates some principles of the systems approach of the second generation:

1. The knowledge needed in a planning problem, is not concentrated in any single head; as there are no specialists for wicked problems. The expertise and ignorance is distributed over all participants. "There is a symmetry of ignorance", the best knowledge is most likely to be with those that are most likely to be affected by the solution.

2. As "nobody wants to be planned at", one needs a kind of maximized involvement or decentralization of decision making.

3. "Transparency and communicability of the planning process", is essential to lay bare the ought-to-be premises of every step, for decisions cannot be justified on professional expertise as they are based on personal judgements.

4. As solutions to wicked problems can only be good or bad, and not correct or false, who is to determine the satisficing criteria. A process of making the criteria objective is thus necessary. "Objectification leads to better understanding, if not agreement". It would help (i) to forget less; (ii) to stimulate doubt; (iii) to raise the right issues; (iv) to control the delegation of judgement; and (v) to believe in the usefulness of the explicit.

5. "There is no scientific planning" it always is political because of its ought-to-be premise.

6. "Planning is not an expertise", but more a role of uncovering problems, rather than offering solutions.

7. Carefully seasoned respectlessness, or "systematic doubt can be a virtue", and can substitute for testing.
8. "Moderate optimism is essential for coming to a conclusion", in solving wicked problems.
9. The model one might use instead of the expert model of the first generation can be called "a conspiracy model of planning", which implies sharing of risk.
10. Whereas the planning process of the first generation could be carried out in confinement in a long series of steps, "the planning process of wicked problem-solving must be understood as an argumentative process".

These are the main principles of the planning process of the second generation. Rittel claims that one cannot be rational, or have a research approach, instead one must make intuitive decisions, that follow no rules. He argues that even though we may follow a rational and systematic approach to problem solving, the ultimate reasons for selecting a solution remain subjective.

In other words the search is not based on a deterministic, hierarchic and static tree structure, but on the functional levels of dynamic lattices that have indeterminate and ever changing relations.

Interestingly enough the recent trend in organizational structures, have moved away from rigid hierarchical or functional relations to the matrix form of organization, where relationships are ever changing, and adjustments to functional requirements can be met more easily. Such a system of organization can be interpreted as an open one, when compared to the more rigid closed structure that preceded it.

It could be argued, that the relations of the people that are involved in building systems, is reflected in the characteristics of the realized system. Further, as society determines the type of desired systems, an open and free society would require corresponding openness and freedom of the building systems it inhabits. However, the desired and the created systems can only match when the users and the doers follow the same organizational principles.

Systems building of the second generation is in this
context mainly an organizational planning problem. The performance specifications of the second generation will have to take this characteristic into account.

POSSIBLE FUTURE DIRECTIONS

Brill (1972) speculates on the direction in which the State of the Art will move. The following are descriptions of present and possible future procedures for development.

A First-Generation Performance Specification is one which develops, elicits or assembles information from users or for users in terms of their performance needs in buildings. It organizes information in such a way that it may be used as a procurement document to which industry may respond.

A First-Generation Building System is a building system which is the first response to a performance specification. It normally involves research and development of a substantial nature by the manufacturers involved. A Building System being a kit of building parts with a set of rules for their assembly into total operating systems to achieve some desired level of performance.

A second-Generation Building System is a first generation building system which, through successful application elsewhere, is reused by other groups as is, or only slightly modified. The components acquire an "off-the-shelf" quality, provided they are used in terms of their rules. Fully open systems, developed through matrix bidding (like SEF in Toronto) have high promise as second generation systems.

A Second-Generation Performance Specifications may be used to procure either (A) Third-Generation Building Systems, or (B) First-Generation Infrastructure Systems.

To procure (A) Third-Generation Building System, a second-generation performance specifications might have some of the following qualities:

1. Attempts to procure substantively higher levels of performance. This implies a research and analysis emphasis
on the user's psychological and social needs.

2. Attempts to further develop "vertical open systems"; open building systems for specific building types.

3. Attempts to develop "horizontal open systems"; open systems which cut across many building types.

4. Attempts to procure satisfactory cost performance over time by development of first cost/life cost bidding formulas. This would imply that the group producing the system has an accounting system which permits trade offs between capital investments and operating costs.

5. Attempts to use units of bid which are themselves performance oriented, rather than "thing" oriented.

To procure (B) First-Generation Infrastructure Systems, a performance specifications would concern itself with the ecology of buildings and groups of buildings. It would attempt to procure performance-oriented, ecologically sound


3. Anti-pollution Systems.

2.7 CONCLUSION: DYNAMICS

The dynamic nature of artificial systems can be understood through organized construct that permits the interpretation of information flows and exchanges. The open or closed interpretations of a system determine its boundary conditions. The concept of structure used to organize systems are: closed boundaries, feedback loops, levels and rates, and within the rates, the goals, apparent conditions, discrepancies and actions or decisions.

Decisions are based on available data, the predicting and valuing systems and the probable and desirable criteria used for making recommendation. The organization of representations, determined in structural and functional terms, is essential for differentiating static from dynamic criteria. Information processing in systems design can be viewed as a planning process or decision making in the prescription-description mode, and its interaction with the design process or problem solving in the analytic-synthetic-evaluation mode.

The systems approach when applied to building problems results in the balancing of resources and constraints against needs and criteria. The controls for optimization and allocation, the potential for innovation, and the rules and interfaces employed, determine the nature of the developed system. The advantages of industrialization have to be balanced by the need for information.

The performance concepts links creation to use. Descriptive or functional requirements are preferred over prescriptive design or constructional requirements. The hierarchic development of performance concepts assist and compliments the steps used in the systems approach. The respective ranges of their applicability however do not coincide totally. This need not be so. Prescription and description forms a continuum that varies in its degree of specificity and content.

With hierarchical arrangements selections can be made advantageously. The rules and representations, and the
characteristics of the systems designer, determine the
dynamic nature of the designed system.

The shortcomings of the systems approach in defining and
solving wicked problems make necessary certain dynamic
shifts that may appear in conflict with the approach itself.
But such inherent unstability is desirable, and essential
for an extension of the implicit concepts.
ON MUTATIONS

3.0 INTRODUCTION
3.1 DEFINING MUTATIONS
3.2 CONTINGENCY THEORY
3.3 INVARIANTS
3.4 ORGANIZATION AND REORGANIZATION
3.5 FRAMEWORK FOR REPRESENTATION
3.6 CONCLUSION
3.0 INTRODUCTION: MUTATIONS

Evolution is the gradual alteration or imperceptible change or shift within a field. When this process of change is itself affected, then a higher order phenomena is implied. Process mutations occur on a meta-level. The mechanism employed is adaptive self-organization, the simultaneous reorganization of structure and function. This is the stuff of revolutions, the jumps in science, of important discoveries or inventions, and the essence of creativity and inductive reasoning.

As mutation occurs on the meta-level, ordinary procedures fail to explain such phenomena. In attempting anticipatory action, one can at the most identify the contingent variables. Determining invariants from such situations falls in the difficult field of correlational analysis. Systems building attempts to synthesize such conditions artificially, thus speeding up natural processes.
3.1 DEFINING MUTATIONS

Process mutations can generally be attributed to induction, or to the synthetic mode of thought. Before attempting to define them, it may make sense to first find out under what conditions they occur and what they imply.

KNOWLEDGE REPRESENTATION AND USE

According to Ackoff (1974): "A person's ability to manage his or her society's affairs depends more on his understanding of and attitude towards the world that contains him than on his problem solving methods. Put another way, his success depends more on his view of the world and the philosophy he lives by than it does on his science and technology." Thus, though problem solving depends upon our science and technology, our ability to use them effectively depends on our philosophy and 'world view', or in other words on the way we represent knowledge.

Knowledge can been classified as prescriptive or descriptive. Further each of these types can be represent by 'a priory' or 'a posteriory' status. This scheme fits well with the four categories of knowledge required for planning and design, as explained by Rittel (1980) (Figure 3.1.1). They are:

1. Factual Knowledge: (Descriptive-A-Priori) It describes what is, was, or will be or become the case, more or less certainly.

2. Deontic Knowledge: (Prescriptive-A-Posteriori) It prescribes what ought to be or become the case. A necessary condition for the existence of a 'Problem' is that an item of Factual Knowledge contradicts an item of Deontic Knowledge.

3. Explanatory Knowledge: (Descriptive-A-Posteriori) Explains why something is, was or will be or become the case. Explanatory Knowledge is needed in planning or design in order to push the search for resolution a step further.

4. Instrumental Knowledge: (Prescriptive-A-Priori)
Know-how pertaining to potential action. It is the knowledge of how to manipulate the world of facts.

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<tr>
<th>A PRIORI</th>
<th>A POSTERIORI</th>
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<tr>
<td>DESCRIPTIVE</td>
<td>FACTUAL K. what is.</td>
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<tr>
<td>PRESCRIPTIVE</td>
<td>INSTRUMENTAL K. how?</td>
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Fig. 3.1.1
Classification of knowledge representation and use.

PROBLEMS OF SPECIFICATION AND REPRESENTATION

We have already seen that prescriptions for an ought-to-be state are undesirable, and that performance specifications of a descriptive sort are more effective in achieving the desired state. Hence, to resolve this apparent contradiction, we can say that, descriptive knowledge should ‘prescribe’ descriptions or representations, whereas prescriptive knowledge must ‘describe’ prescriptions or specifications.

As explanatory knowledge is an a-posteriori fact, there will be problems of specification, which is an a-priori function. Similarly, as instrumental knowledge is an a-priori fact, there will be a problem of representation, which is an a-posteriori function. For similar reasons, deontic or ought to be knowledge contains both problems of specification and representation.

Viewed another way the problem of representation is the search for the problem, and the problem of specification is one of controlling the problem. Search and control can thus be considered the real problems. And as a search itself implies control, and control itself requires a search, they are intrinsically interrelated.

Problem solving has much to do with differentiating or making explicit the issues of search and control. On one level design can be considered the search for a solution,
and planning the setting up of controls, and on another level the converse holds true. The search and control mechanisms, with their dynamic functional and structural attributes can also be ordered into hierarchical organizations. Such ordering is necessary from a practical point of view, as large problems have to be decomposed before they can be solved. It is this method of decomposition that determines the nature of the hierarchical organization.

WHAT ARE PROCESS MUTATIONS?

Mutation is defined as, (i) the act or process of being altered or changed; and (ii) an alteration or change, as in nature, form or quality. Mutant is a biological term for an individual or organism differing from the parent strain or strains as a result of mutation.

Mutants can thus be differentiated according to whether they have undergone alterations or changes. Alteration implies retaining the original organization or at the most involves a reorganization, whereas change may necessitates a totally new organization. Alteration is the result of adaptive self-stabilization, whereas change is the result of adaptive self-organization. Both are systemic state properties of a dynamic nature.

As mutation is itself an act or a process, it follows that process mutations are second order acts or processes. Hence, if design is taken to be the initiation of change, then design mutations would imply second or higher-order changes operating on a meta level.

Thus if design and planning deals with representations, specifications and their translations, then process mutations deal with the transformations of these very same aspects.

Unlike with alterations, there appears to be no absolute way of measuring changes. An analysis of process mutations would thus have to be entirely subjective or relative. For alterations one would normally discount time but not
sequence, whereas for change time is the dominant characteristic and sequence becomes irrelevant.

Thus with alterations one is most likely to ask the question how, whereas with changes one would ask the question when. Alterations thus involve functional 'shifts', whereas changes involve structural 'jumps' that may result in totally new functions (Figure 3.1.2).

Fig 3.1.2
Alteration and change through transformations.

Process mutations or changes in problem solving are thus a result of changes in the problem space, or in its representation, and/or changes in the stated solution or in its specification (Figure 3.1.3).

Fig. 3.1.3
Schema for problem and solution representation and specification, and problem solving methods.
Fig. 3.1.4
Examples of Cartesian Transformations (Thompson 1961).

Fig. 3.1.5
Interpretations of Crustacia and Fish (Thompson 1961).
Fig. 3.1.6
Generalized Cylinders and an epistemology of axis variations suffice to support procedures which identify the standard Greek vase type of areheological interest.
Fig. 3.1.7
Translations of facial expressions (after Albrecht Durer).

Fig. 3.1.8
Interpretation of Human, Chimpanzee and Baboon Skulls.

Fig. 3.1.9
Three houses by Frank Lloyd Wright and their common graph of spaces and room linkages (from March and Steadman 1971).
3.2 CONTINGENCY THEORY

Contingency theory investigates the relationship between structure and situation, and the associated flow of information. It opposes the notion of a universal structural form, and instead seeks to identify particular alternative structures that are most appropriate under a specific set of conditions.

Woodward (1965), in a pioneering study of industry gave evidence that a firm's structure was closely related to its technical system of production. Mass production firms seemed to require a formal type of structure, whereas firms in unit and process production seemed to require a looser structure, that relied more on mutual adjustment. Contingency theory applies to all kinds of design or planning problems.

Contingency theory is not required for providing routines, but instead provides support for nonroutine operations. As such operations are critical, a design process must include plans for procedures that respond quickly and efficiently to any contingent event that can be anticipated. These operations must be exercised, in the event that one of the anticipated contingencies occurs.

Effectiveness of organization results from a match between situation and structure. There is no one best structure, but rather different best ones under different conditions. The complexity of the environmental conditions as well as the predictability are important for high performance. Under complex and dynamic situations more extensive structural differentiation and use of link mechanisms or network devices for coordination are required, while simpler and more stable situations require less differentiation and need a hierarchy for coordination. Success seems to stem not from any single structural device, such as design by objectives, decentralization of decisions, or on a planning system.

HYPOTHESIS OF STRUCTURAL EFFECTIVENESS

Two important and distinct conclusions can be reached
about the effectiveness of structural organizations:

1. The "congruence" hypothesis states that effective structures require a close fit between the contingency variables and the design parameters.

2. The "configuration" hypothesis states that effective structures require an initial consistency among the design parameters.

The two hypothesis can be combined to form an "extended configuration" hypothesis which states that effective structuring requires a consistency among the design parameters and contingency factors.

The relations between contingency factors and design parameters are 'correlational'. That means that causation cannot be determined; there is no way to know whether the contingency factor gives rise to the design parameter, or vice versa, or the two emerge together, as suggested by the extended configuration hypothesis. Never the less since structures seem easier to change, causation is assumed to flow from situation to structure, from contingency factor to design parameter. That is, the contingent factors are treated as 'independent' variables. The design parameters are the dependent ones, and hence are assumed to be contingent on the structural organization.

Figure 3.2.1 shows the contingency variables and their categories. The dependent variables are the design parameters. In addition, it is helpful to include certain intermediate variables, that stand between the independent and the dependent ones.

The independent variables describe the impact of problem space environment on structure by its effects on the information that has to be processed to make decisions (Galbraith 1973). An alternate way is to think of the impact of environment by the effects on the analyzability of search processes and the number of exceptions encountered. The intermediate variables concern the nature of issues to be tackled by the organization.

1. Comprehensibility, concerns the ease with which the
<table>
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<tr>
<th>INDEPENDENT CONTINGENCY VARIABLES</th>
<th>INTERMEDIATE ISSUE RELATED VARIABLES</th>
<th>DEPENDENT STRUCTURAL VARIABLES</th>
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<td>ORGANIZATIONAL Variables</td>
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<td>Specialized Knowledge</td>
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<td>Persistence of Organizational Size of Organization &gt;</td>
<td>Comprehensibility &gt; of the Issue</td>
<td>Training and Routines</td>
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<td>Technical Systems and Regulations &gt;</td>
<td>Predictability of &gt; the Issues</td>
<td>Formalized Responses</td>
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<td>Technical Systems Sophistication &gt;</td>
<td>Diversity of the &gt; Issues</td>
<td>Size of Subproblems</td>
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<td>Environmental Stability &gt;</td>
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<td>Grouping of Subproblems</td>
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<tr>
<td>Environmental Complexity &gt;</td>
<td></td>
<td>Planning and Control System</td>
</tr>
<tr>
<td>Environmental Diversity &gt;</td>
<td></td>
<td>Link Mechanism or Networks</td>
</tr>
<tr>
<td>Environmental Hostility &gt;</td>
<td></td>
<td>Vertical Structuring</td>
</tr>
<tr>
<td>HUMAN Variables</td>
<td></td>
<td>Horizontal Structuring</td>
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<td>Initiators</td>
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<td>Needs and Requirements</td>
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</tr>
<tr>
<td>Fashion or Trends</td>
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</tbody>
</table>

Fig. 3.2.1
The independent, intermediate and dependent variables effecting structural organization and problem solving.
issues can be tackled. This is most influenced by the independent variables of environmental complexity and the technical systems organization. It in turn determines the intellectual load on the organization, in the form of expertise and hence affects the dependent variables of specialization and structural decentralization.

2. Predictability, concerns the a-priory knowledge that the organization has of the issues it must tackle. Persistance and size of the organization, as well as stability and absense of hostility in the environment, and the degree with which technical systems regulate activity are all determinants. It leads to standardization; formalized responses, planning and control systems, and training or routine.

3. Diversity, describes how varied the issues are that have to be tackled. Environmental diversity effects it directly, and size and shape of organization indirectly. Issue diversity influences the choices for subproblem grouping, thus formalizing responses, link mechanisms and network devices.

4. Speed of response, describes the speed with which the organization must respond to its environment. Environment hostility effects it adversely, as well as the initiators and organization to a lesser extent. It in turn influences the design parameters of decentralization, formalization and subproblem grouping.

PROBLEMS IN INTERPRITING CONTINGENCY VARIABLES.

Several problems crop up while studying contingency variables.

1. Structural changes lag situational changes significantly. A stable environment must become significantly dynamic before the organisation will respond. Likewise, heavy workload prevents frequent changes in formalized organization.

2. Multiple contingencies which have divergent influences are another source of problems, and cause difficulties in
3. Last is the problem of context, often it is difficult to determine which of the contingency factors are responsible for some change in structural organization.

One can see that whether the design problem involves the structural organization of people or processes, the characteristic influences of the contingency factors remain largely the same. Contingency factors are correlational, that is two or more of them occurring at the same time cannot be causally related to each other, but result in the dependent structural variable. It is such uncertain situations that are largely responsible for solutions that are satisficing rather than optimizing.

The contingency factors also appear responsible for process mutations, in that they encourage unprecedented combinations that may not be foreseeable by contingency plans. As already mentioned, it is difficult to assess whether the contingency variables that influence the problem space representation precede changes in the specifications and solution set or vice versa. The important point is that mutations themselves appear to depend on correlations between independent contingent variables.
3.3 INVARIANTS

Anything that does not vary or change with time is invariable. An 'invariant' however, is more difficult to describe, as it defines a relationship that may itself be variable. It would make more sense to call them structurally dependent relationships.

INVARIANT AND CONTINGENT CHARACTERISTICS

Invariant relations differ from contingent relations in that they are dependent on causality, unlike independent correlations. Invariant causal relations can be deterministic or probabilistic. This depends on the type of level or levels permissible, and to the degree to which they are fixed or prescriptive or variable and descriptive.

As the fixed or prescriptive levels are often predetermined in problem definition or solving, they include a bias of an a-priori kind, and are often faulty representations. Therefore an attempt should always be made to defer judgement as long as possible, or till an opportune state. Till then a probabilistic approach of a variable and descriptive kind should be adopted.

On the other hand, the contingent characteristics of independent correlations that have variable levels of a descriptive type, require more deterministic formulations. In other words, the contingent characteristics should be translated into invariant relations, if possible. The less descriptive and the more prescriptive the contingent variables become, the better the chances of successfully meeting emergency conditions, or taking advantage of favourable situations. But even under such conditions, contingent factors cannot become entirely fixed and prescriptive. They will continue having variable and descriptive level, but will include more invariant characteristics.
Invariant and contingent relations.

Figure 3.3.1 illustrates the converging tendencies of the predetermined or an a-priori situation, and the environment determined or an a-posteriori situation. Thus both the fixed prescriptive levels and the contingent variables tend to meet at the desired state, which has invariant characteristics of the descriptive type. Effective handling of the contingent variables (see Ehrenkrantz 1970), is a prerequisite, or at least a determining factor that influences the success in problem solving, whereas the invariants actually determine the problem solving methods.

The differences between prescriptive or traditional specifications and descriptive or performance oriented specifications have already been noted. If one were to consider the relations between specifications and resources, two questions arise. One involving 'type' and the other 'availability'. As prescriptive specifications determine the type of resource, the issue of availability becomes secondary. No problems are experienced with resource type if tradition is followed, as it already exists in a dependent relation. But the resource may not be available, and hence availability depends on correlation. On the other hand descriptive or performance oriented specifications assume availability of resources as a dependent relation, and the resource type which will have to be developed relies on correlation. This shows that the two resource factors are inversely related to specifications. (Figure 3.3.2).
<table>
<thead>
<tr>
<th>RESOURCE FACTORS</th>
<th>RELATIONS</th>
<th>DEPENDENT</th>
<th>INDEPENDENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE</td>
<td>Prescriptive S.</td>
<td>Descriptive S.</td>
<td></td>
</tr>
<tr>
<td>AVAILABILITY</td>
<td>Descriptive S.</td>
<td>Prescriptive S.</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3.3.2
Specifications and their relations to resource factors.

Resources can be differentiated according to the hardware or software requirements of the system. They include the following:
1. What the system is made of.
2. How the system is put together.
3. What controls the system.
4. How the system performs.

The important issue of determining the invariants, is always decided by the systems designer on the basis of type and availability of resources. Depending on these factors he decides as to whether or not to undertake the design of the system, or if he is in control, at what level he could start defining the system. The building systems designer or developer, offers a typical example. Figure 3.3.3 differentiates the defining and designing stages in three cases. One can see that only when the contingent factors are evenly shared by the project designer and the product designer, such as at the subsystem or component level, will the resulting system be truly open. One could say that in both conventional and closed systems, the tendency to convert contingent factors, by the project designer in the first case and the product designer in the other, brings about invariant situations for one party, which is reflected in the product, that adversely effects the other party, in some other way. Lack of innovation in conventional systems and to much standardization in closed systems, may be efficient invariant procurement methods, but may effect the users adversely.
Fig 3.3.3
A comparison of systems design types. Relating invariant and contingent factors with resources variable.
3.4 ORGANIZATION AND REORGANIZATION

This section investigates search strategies as structures for organized problem solving. Reorganization can be considered a special case of organization.

SEARCH AND CONTROL

Problem solving necessitates finding paths through network or tree structures. The intervening "nodes" and available "branches" form the elements of search grammar. Problem solving involves two paths, one being a trace through the explored domain or problem space, the other being a trace of the method employed. The results depend jointly on the structure of the domain and on the structure of the problem solver.

"Search" focuses on methods for exploring the tree structures that frequently describe problem domains. "Control" focuses on how the problem solver chooses to shift attention among its subprocesses (Figure 3.4.1).

There is no clear boundary dividing search from control. The issue is one of focus or point of view. Both search strategies and control decisions are essential for successful problem solving. Control can be considered the special case of search, where the search locus moves through the problem solver's individual method.

Fig. 3.4.1
Search and control representations after Winston (1979).

SEARCH: EXPLORING ALTERNATIVES

Search techniques fall under three main headings:

1. "Basic Search" includes such classic notions as
Depth-First and Breadth-First search, as well as various Hill Climbing and optimal path methods.

2. The "Range Construction" approach.

3. Techniques of "Game-playing". These include the minimax, alpha beta, and heuristic pruning methods.

BASIC SEARCH METHODS

The search problem of determining a good path, such as for traversing a city without a road map, involves exploration. First, there is the effort in 'finding' either some path or the best path. And, second, there is the effort actually expended in 'traversing' the network (Figure 3.4.2A).

![Diagram of a basic search problem as a tree]

Fig. 4.3.2A
A basic search problem.

![Diagram of the network as a tree]

Fig. 4.3.2B
The network as a tree.

The effort expended on search, and hence the quality of a solution path, is directly related to the effort expended in using the solution, and the frequency with which it will be used.

The search for an optimal solution, requires a bookkeeping scheme that will permit the orderly exploration of all possible paths, without cyclic repetitions within the network. If a node is not to be traversed twice, the network can be represented as a tree with the same number of levels as there are nodes in the network (Figure 3.4.2B).

"A DEPTH-FIRST search dives deeply into the search tree". The idea is to begin with an initial node, work
forward by selecting any alternative at every visited node, and completely ignore all other nodes on the same level. The convention of working from left-to-right is normally followed. If the end of the first branch fails to lead to the destination node, one backs up to the first previous node with alternatives and continues (Figure 3.4.2C). The procedure is inefficient for large networks, as a lot of effort may be expended at levels lower than the location of the solution node.

![Diagram](image)

**Fig. 4.3.2C**
Depth-First search.

![Diagram](image)

**Fig. 4.3.2D**
Breadth-First search.

"**BREADTH-FIRST searches push uniformly into the search tree**, by looking for the destination among all nodes at a given level before using the branches descending from those nodes to push on (Figure 3.4.2D). Although the Breadth-First idea is careful and conservative, it can be wasteful, if all the destination nodes are at more or less the same depth, and in that case works harder than Depth-First search.

As search trees are often very large, techniques of exhaustive enumeration such as Depth-First and Breadth-First searches are extremely inefficient. Fortunately there are alternate strategies for reducing searches.

"**HILL CLIMBING is a Depth-First search converted by local measurement**. Search efficiency improves if there is some way of ordering the branches under each node, so that the most promising are explored first. The problem must
Fig. 3.4.3A
Hill Climbing is Depth-First plus a method of ordering alternatives at each point.

Fig. 3.4.3B
The foothill problem of Hill Climbing.

Fig. 3.4.3C
The ridge problem of Hill Climbing.

Fig. 3.4.3D
The plateau problem of Hill Climbing.
confirm to an abstraction in which there are some adjustable parameters and a way of measuring the performance associated with any particular set of values for the parameters. The required measure may be absolute or relative, precise or approximate. Hill Climbing is Depth-First search plus a method for ordering the alternatives at each decision point. Movement proceeds through the alternatives which offers the best improvement to the situation in one step. The search continues till no higher measure is possible (Figure 3.4.3A). This converts the search into a dynamic process (see section 2.1).

Though Hill Climbing is generally useful it does have problems, such as those associated with foothills, ridges and plateaus. The foothill problem traps the solver with a solution that isn't the best (Figure 3.4.3B). The ridge problem is more subtle, and requires an increase in the number of search directions or a change in the size of steps (Figure 3.4.3C). The plateau problem is even more difficult to handle, as the problem space is uniform but for a few exceptions. Improvements in local operations completely break down (Figure 3.4.3D).

Hill Climbing breaks down completely when there are many dimensions. Performance functions that combine the weighed averages of all the parameters at each step do not change the initial situation, nor are they an effective means of evaluation. The Hill Hlimbing metaphor can deflect attention from description and representation.

Hill Climbing can itself be used for evaluation. It speeds recognition in similarity space, such as when a near miss test model suggests the use of similar models that may match the unknown model. Here the initial matching is not a failure, it is a knowledge probe. The analogy metaphor fits because the decision about which neighbour to use is determined by comparing descriptions of differences.

"BEST-FIRST search probes forward from the best partial path". In Hill Climbing, forward motion is always from the last decision through the seemingly best decision.
Best-First search is a slight but important variation, where forward motion is from the best node so far, no matter where it is in the partially developed tree (Figure 3.4.4). Since motion is always in the direction that seems most economical, it is generally more efficient in path length than Depth-First or Breadth-First searches.

![Diagram of Hill Climbing and Best-First Search]

**Fig. 3.4.4**
Best-First search differentiated from Hill Climbing.

"The BRANCH-AND-BOUND strategy probes forward from the least-cost partial path". The method begins with the shortest path which is extended one level, creating as many new incomplete paths as there are branches. These new paths are then considered along with the remaining old ones and again the shortest is extended. This is repeated until the destination is reached along some path. Since the shortest path is always chosen for extension, the first path to reach the destination will be the optimal (after comparison with one last step). But, this may not guarantee the shortest search. There may always be a solution path that is closer
to the origin than the optimal solution.

Search strategies with feedback and estimates of the remainder, act as dynamic systems, and are subject to the classical fluctuations of negative feedback. This is even more true, when there are many interdependent levels in the system or simultaneous searches. If the estimates are pessimistic, there can be no error in ultimate path selection, as some completed nonoptimal path cannot be shorter than an incomplete optimal path. If the estimate is zero, it wouldn't affect the result, as the strategy itself is to minimize.

"The AND/OR TREE idea descends from two heuristics. The first tries to convert a hard problem into one simpler problem, and the second tries to convert it into several simpler subproblems".

In the first case, there may be more than one simpler problem that is equivalent to the hard one. But a simpler problem may in its turn be further simplified, thus generating a tree, in which a solution to any end node would solve the original problem at the top. Such a structure is called an OR tree (Figure 3.4.5A).

In the second case, the hard problem is first divided into subproblems that all require solutions to solve the original problem. The subproblems may in their turn be divisible, and so on, till a tree is formed, and for which all terminal subproblems require solutions to solve the original tough problem. Such a structure is called an AND tree (Figure 3.4.5B).

And/or trees are mixed collection of pure AND nodes, which show how a problem can be transformed into an equivalent set of subproblems, and pure OR nodes, which show how a problem can be transformed into any one of a set of equivalent problems (Figure 3.4.5C). As AND/OR trees can be large, one part of the problem solver is to avoid full development of the tree implied by the problem. Looking at problem solving as search can draw attention away from making better problem descriptions which make the search
trivial.

Fig. 3.4.5A
An OR tree.

Fig. 3.4.5B
An AND tree.

Fig. 3.4.5C
An AND/OR tree.

Fig. 3.4.6
The junction combination for the physically realizable trihedral vertexes. The + symbol labels convex edges; the -, convex; and the arrow, boundaries.
RANGE CONSTRUCTION TECHNIQUE

The Range Construction technique can be demonstrated by solving the problem of labelling the lines of a three dimensional drawing according to the eighteen possible representations of trihedral vertexes (Figure 3.4.6).

Ordinary search is poor at finding line labels for drawings. In working through arbitrary drawings, there will be situations where more than one physical arrangement is consistent with the interpretations assumed at previously visited neighbouring junctions. Hence a choice must be made. This may either lead to a complete analysis, or to inconsistencies. Figure 3.4.7 shows such a situation.

As the junctions in the drawings may be visited in different sequences, the search trees generated will vary in size and shapes (Figure 3.4.8). If each node has only one branch, a definite representation could be made on the first visit. But this does not always happen.

The Waltz algorithm iterates towards compatible junction labelling. Theoretically, correct solutions could be found by Depth-First or Breadth-First search, but combinatorial explosion prohibit this in more complex scenes. One way of solving this problem, is to maintain a list of labelling possibilities at each junction. On the first visit, all physically possible arrangements are selected from the junction list and stored. These arrangements form the constraints for subsequent visits, thus reducing the permissible possible arrangements. The process iterates till each junction has only one possible label (Figure 3.4.9).

Sometimes labelling choices correspond to permanent ambiguities, as in Figure 3.4.10. In which case the satisfactory solution will have to be determined from the labelling criterion.
Fig. 3.4.7
The drawing shows two labels remain possible at each of the remaining forks.

Fig. 3.4.8
The size and shape of the search tree is determined by the order in which the junctions are considered.

Fig. 3.4.9
An application of Waltz's range construction procedure for labelling scenes.
Fig. 3.4.10
Labelling choices corresponding to permanent ambiguities.

GAME PLAYING TECHNIQUES

Game playing is another type of search. According to one view, hardly any knowledge is useful beyond what is needed to look ahead through many rounds of moves and countermoves. Whereas, others claim that strategic play based on patterns, is beyond the capacity of the approach based solely on looking ahead.

The adversary nature of games makes their searching trees different. In the look-ahead method, the possible legal moves at any point in the game or node, are given by what is known as the branching factor. If there were ways to rank these branches, the choice of moves would be simple. Unfortunately this is not so, and other less reliable evaluation techniques such as simulation are required. But combinatorial explosion prohibit such evaluations for more than a few extensions of moves and countermoves.

MINIMAXING is a look ahead method for determining moves from a partially developed game tree with a static evaluator which maps situations into a single, advantage-specifying number. One player works towards the higher numbers, seeking advantage, while the opponent goes for the lower numbers. The process by which the scoring information passes up the game tree is called the minimax process since the scores at a node are either the minimum or maximum of the scores at
the node immediately below (Figure 3.4.11A). Mapping overall quality into a single number has a serious defect, as it can say nothing about how the number was determined. The method can also be expensive, as all possible paths have to be generated and statically evaluated. Which costs more depends on the details of the static evaluator and move generator used.

The ALPHA-BETA technique prunes the search tree. Some work can be avoided by augmenting the minimax idea with the alpha-beta procedures. Figure 3.4.11B shows that there is no need to fully explore the right side of the tree because there is no way the result could alter the move decision. Once movement to the right is shown to be worse than movement to the left, there is no need to see how much worse. In general using the alpha-beta generator means fewer move generations and fewer static evaluations. It is somewhat similar to the branch-and-bound idea in that some paths are demonstrably nonoptimal even though not followed to the limit of look ahead. The alpha-beta search speedup technique guarantees as good an answer as can be found by complete, exhaustive maximizing, but it only wins a temporary reprieve as the numbers required become impossibly large with increasing depth.

HEURISTIC SEARCH techniques are used in combination with alpha-beta pruning as additional weapons against explosive growth.

'Limiting Breadth'. A brute-force way of reducing the effective branching factor in a game tree is to ignore the less likely possibilities. Such a plausible move generator is generally used anyway in connection with the alpha-beta method, therefore it is easy to single out the most likely descendant from any node of study.

'Disaster Cutoff'. Another way of limiting search down through bad moves depends not on the simpler portion of the move in the plausible ranking but rather on some accumulated plausibility value. This makes the shape and size of the tree sensitive to the particular situation. If only one line
Fig. 3.4.11A
Minimax method.

Fig. 3.4.11B
Alpha-Beta procedure.

Fig 3.4.12
The horizon effect foils search oriented game procedures when disasters can be delayed but not prevented.
of play makes sense at all, it would be the only one pursued, and would therefore be followed to greater depth. On the other hand, if any line of play seems equally plausible, then this method tends to allocate resources among them equally.

‘Futility Cutoff’. Pushing the tree down equally through moves of equal plausibility makes sense. But after some solid evaluations are made, it may well develop that considerable search savings can be had by rejecting partially explored moves that can at best offer slight improvement on some fully explored moves.

‘Feedover Condition’. So far the techniques limit tree growth. Sometimes it is useful to go the other way and extend the tree when circumstances warrant. There are a number of so-called feedover conditions that can cause a configuration to be particularly dynamic and deserving of further exploration.

‘Secondary search’. After all ordinary search is complete with the alpha-beta method, the various heuristic methods and feedover, all playing their assigned parts, it is often good to grow a secondary tree down from the node judged to be at the bottom of the optimal path. Doing this double checks the accuracy of the value assumed for the target node. The hope is that the two scores will be roughly the same, and cause no surprises. In cases where this is not true, the horizon effect may cause unnecessary losses or delays (Figure 3.4.12).
3.5 FRAMEWORK FOR REPRESENTATION

Minsky (1975) states that "analysis is based on the interactions between sensations and a huge network of learned symbolic information. While ultimately those interactions must themselves be based on a reasonable set of powerful principles, the performance theory is separate from the theory of how the system might originate and develop".

He suspects that the usefulness of parallelism may have fundamental limitations at higher levels of cognitive processes, and that most successful symbolic theories use hypothesis formation and confirmation methods that seem, on the surface at least, more inherently serial. Theories of human thinking and schemes for intelligent machines, need not be separate, as neither domain contains satisfactory explanatory theories. Thus, for the time being one must concentrate on sufficiency and efficiency rather than necessity.

Minsky hypothesises that seeing and imaging result in assignments to frame terminals, and imagination permits choice of detail and variety of assignment. Frames are stored in long term memory with weakly bound default parameters, that permit analogies (synthetic models), generalizations (analytic interpretations of data), and judgement (valuation and prediction) of external data involving weak choices. Such reflections according to Piaget (1956) are thoughts raised to the second power. "Concrete thinking is the representation of a possible action, and formal thinking is the representation of a representation of possible action". There are similarities between Piaget's idea of concrete operations and the effects of applying 'transformations' between frames of a system. The understanding of transformations is necessary, as they contain knowledge needed for more sophisticated reasoning.

Minsky makes reference to Chomsky; "Generative grammar would be a summary description of the exterior appearance of those frame rules - or their associated processes - while
the operators of transformational grammars seem similar enough to some of our frame transformations". In his paper on K-line theory, Minsky uses systems theory to develops the above into a dynamic hierarchical system. Such a theory can effectively represent all types of knowledge, including those needed for planning and design.

THE HIERARCHY OF FRAMES

The tentative working hierarchy of frames, and their classification and ordering into a system is as follows:
1. Surface syntactic frames: Mainly verb case. Propositional and word-order indicator conventions. Deontic or ought-to-be knowledge forms the basis of productions that can be derived from propositional calculus/predicate logic (see McCarthy, 1953 and Moucka, 1979).
2. Surface semantic frames: Deep syntactic frames perhaps. Action-centred meaning words. Qualifiers and relations concerning participants, instruments, trajectories and strategies, goals, consequences and side-effects. Instrumental knowledge is expressed best by using conventional production rules (see Newell and Simon, 1972, Davis and King, 1975, etc.).
3. Thematic frames: Topics, activities, portraits, settings. Outstanding problems and strategies commonly connected with topic. Factual knowledge deals with representations or models depicting limitations in systems (Habraken, Alexander and Ehrenkrantz have develop different aspects of frameworks at this level in the hierarchy).
4. Narrative frames: Stories, explanations, and arguments. Conventions about foci, protagonists, plots, development, etc., with the purpose of causing the listner to construct a new Thematic Frame in his own mind. Explanatory knowledge emphasizes procedures that permit reinterpretations (see Kim, 1980 for countermodelling strategies).

When frames encounter trouble the adjustment mechanisms are as follows:
1. Matching: When nothing more specific is found, one can
attempt to use basic associative memory mechanisms. This succeeds only in relatively simple situations, but can play a supportive role in the other tactics.

2. Excuse: An apparent misfit can often be excused or explained. This happens when all but a few aspects match.

3. Advice. The frame contains explicit knowledge about what to do about trouble. 'Similarity networks' embody such knowledge.

4. Summary. If a framework cannot be completed or replaced, one gives it up. But first one must construct a well-formulated complaint or summary to help whatever process next becomes responsible for reassigning the subframe left in limbo.

Issues such as structure-function organization, analogies and alternative descriptions, control and verification are raised elsewhere.

Representation of knowledge are variously called, frames (by Minsky), schemas (by Simon), constructs, organizations, mental images, world views and so on, which vary in their degree of specificity.

REPRESENTATIONS

Figures 3.6.1, 2 & 3 are examples of thematic frameworks for representing aspects of the design process. Figures 3.6.4, 5, 6 & 7 are a sequence of narrative frames that can be used to establish an argument for creating a new thematic frame for the purpose or organizing the interacting groups of a project. Such representations are essentially static. Figures 3.6.8, 9 & 10 represent dynamic relations as well (in these examples time varying). It is possible to create frames that represent both macro and micro aspects of such interrelationships of the systems building process. Examples on the macro level of the hierarchy have already been covered. Those on the micro level may depict work relationships, such as in assembly, different aspects of performance in use, or during maintenance, depending on which specific domain has to be tackled. The development of
expert systems, as we shall see later on, adds another dimension to such representations.
Fig. 3.5.1
A schematic outline of the states, systems, activities and resources as related to the general analysis-synthesis-evaluation model of the total building process.
Fig. 3.5.2
Framework of the supersystem of activities, as a system of realization of development.
Fig. 3.5.3
The pragmatic and ideal approaches to problem solving are closely related to the nature of the problem space. These two schemes are essentially representations of the alternative backward and forward chaining processes.
Fig. 3.5.4
Organigrams of the traditional building system.

Fig. 3.5.5
Organigram of the British School Consortia.

Fig. 3.5.6
Organigram of the performance based procurement system (SCSD).

Fig. 3.5.7
Organigram of the French Models approach.
FRAMEWORK FOR COMPAIRING DEVELOPMENT AND EXECUTION

EVENTS INVOLVING 1-5 PARTIES
AN EXISTING AGENCY (E.G., CLIENT/OWNER)
AN "AD HOC" OR OUTSIDE PARTY BROUGHT INTO THE PROGRAM
A PARTY WHOSE INVOLVEMENT TERMINATES
A CONTINUING PARTICIPANT OR PROGRAM
INTERMITTENT INVOLVEMENT
PARTICIPATION OF TWO OR MORE PARTIES

Graphic symbols for Figures 3.5.8, 9 & 10.

COORDINATING AGENCY

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1961
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1962
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1963
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1964
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1965
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1966
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1967

Fig. 3.5.8
Fig. 3.5.9
Study of Educational Facilities (SEF). Toronto, Canada.
First completely open system for schools.

Fig. 3.5.10
Recherches Ameragements Scholaries (RAS). Montreal, Canada.
3.6 CONCLUSIONS: MUTATIONS

If design is the initiation of change, then mutations are second or higher-order changes. Thus if design and planning deals with representations, specifications and their transformations, then process mutations deal with the changes or transformations of these very same aspects.

Contingency theory investigates the relationship between structure and situation, and the associated flow of information. Effective structuring requires congruence between contingency variables and design parameters, and consistency among the design parameters. Independent contingent variables effect the dependent structural variables through intermediate issue related variables. Their interpretation and representation will thus effect the degree of change.

Invariant relations differ from contingent relations in that they are dependent on causality, unlike independent correlations. It is the matching of prescriptive-descriptive with invariant-contingent variables that determine desired states. The matching of resources and invariants with constraints and contingency determines the characteristics of mutant process and the produced system.

Reorganization can be considered a special case of organization. Search strategies are effective ways of structuring organized problem solving. They include basic search methods, the range construction approach and game-playing techniques. Each of these has its appropriate applications in systems building and system evaluation.

The evaluation of systems performance is often independent of systems development, but depends on the interaction between sensation and acquired symbolic information. The ability to understand such information depends on the framework of representation used. Such representations use the hierarchically structured concepts of ought-to-be, instrumental, factual and explanatory knowledge. These concepts can be attributed different functional levels such as proposition, production, rule or
pattern, and representation, which can be derived for or from any specific domain in question. The degree of precision of the framework for representation will determine the accuracy of prediction or evaluation.
ON SUPPORT

4.0 INTRODUCTION
4.1 CONTROLLING ATTENTION
4.2 PROTOCOL AND ARGUMENTATION
4.3 INFORMATION TRANSMISSION
4.4 PROJECT ORGANIZATION AND CONTROL
4.5 EXPERT SYSTEMS
4.6 CONCLUSION
4.0 INTRODUCTION: SUPPORT

The mechanisms of "search", enable the system to explore networks of situations defined by the environment. In "control", the focus shifts towards mechanisms that determine how a system shifts attention among its own procedural specialists.

The General Problem Solver and the Production System ideas are both examples of control through so-called "demons". Some people believe that human thought is largely controlled by demons as well.

Architecture needs the support of demons. Their discovery and use is essential for its survival.
4.1 CONTROLLING ATTENTION

There is a tendency to assume that complex behavior requires complex answers. How often this is true remains open to question. Simon points out that the apparently complex behavior of ants involves control decisions that are simple and few in number. An environment-driven problem solver often produces behavior that is complex only because a complex environment drives it. It is easy to overestimate the degree of control sophistication required for intelligent behavior at the same time the description and representation problems are underestimated. This problem can be avoided by knowing what it means to understand control.

Control schemes can be classified according to how they satisfy three basic needs.

1. There must be some method for deciding which procedure to use.
2. There must be some way of supplying the active procedure with information.
3. There must be some means by which the active procedures can offer a conclusion.

MEANS END ANALYSIS AND THE GENERAL PROBLEM SOLVER

The General Problem Solver notion embodies a strategy for selecting 'operators' to reduce the differences between the 'current states' and the 'goal states'. The current state represents a collection of facts that specify the problem and the current position. Similarly, the goal state is represented by a collection of facts and the desired end position. The General Problem Solver, devised by Newman and Simon frequently goes by the acronym GPS, and is sometimes called Means-End Analysis.

The key idea in GPS, is to operate on differences. Each of the operators is selected because it is believed relevant to reducing the difference between the state in which it was applied and the goal state. But, in some instances there is no built-in mechanism to prevent the problem solver from actually moving further away from the goal. Further, nothing
prevents getting into a state where apparent distance to the goal is short, but where actual distance is extreme. This occurs when the difference measure is crude and ignores many facts in getting from one state to another.

If an operator relevant to reducing some measured difference cannot be applied because application requires some state characteristic not exhibited by the current state, then it may be desirable to seek a nearby adjacent state where it can be. Getting to the adjacent state is a new problem for a new copy of the General Problem Solver. It makes sense to set up a new problem, and work on the new problem knowing that its solution helps address the original problem.

Finally, there may be situations for which no operator can be found that seems relevant to forward motion and a dead end is reached. When this occurs, the last operator is withdrawn, and a new path sought from the previous state. This automatic backup may lead to the repeal of several steps. The GPS control structure effects a depth-first search of state space.

A 'difference-operator table' records which operations are relevant to each recognized difference, as well as specifies the 'prerequisite condition' (Figure 4.1.1).

<table>
<thead>
<tr>
<th>DIFFERENCES</th>
<th>OPERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>use A</td>
</tr>
<tr>
<td>above X</td>
<td>*</td>
</tr>
<tr>
<td>between X &amp; Y</td>
<td></td>
</tr>
<tr>
<td>between Y &amp; Z</td>
<td></td>
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<tr>
<td>below Z</td>
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<tr>
<td>be at A</td>
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<tr>
<td>be at B</td>
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<td>be at C</td>
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<tr>
<td>be at D</td>
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<td>be at E</td>
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</table>

**PREREQUISITE CONDITIONS**

Fig 4.1.1
A difference-operator table.
While operating, GPS selects each operator because it spans some distance from the current state towards the goal state. Since the new location normally lies far short of the goal, a long chain of operations may develop. Working from initial state towards the goal is called 'forward chaining', and the reverse is called 'backward chaining'. Normally GPS does forward chaining rather than backward chaining. When forward chaining, the distance from the current state to the adjacent state, is reduced by 'recursion'. The distance between the second intermediary and the goal state is then reduced by 'iteration'. With only small differences, it is possible to work backwards from the goal state instead of forward from the initial state. The shape of the state space helps determine whether forward chaining or backward chaining is better. Fan in towards the goal state calls for forward chaining and fan out for backward chaining.

GPS involves several control ideas:

1. Operators are selected by way of observed differences. Implicit, rather than explicit, procedure selection is preferred. Difference tables are cumbersome for large systems.

2. It iterates through test-operate sequences until finished. This is an abstract form of feedback.

3. Forward-moving iteration is unwound in depth first fashion when encountering dead ends. It exhibits automatic backup.

4. GPS applies copies of itself on subproblems, hence it involves the notion of recursion.

Basic control questions, such as, where are inputs to procedures found and how are the outputs delivered, are not answered by GPS. Such problems can be overcome with an operator consisting of three lists of facts: (i) the prerequisite list, which contains facts that are true if the operator is to be applied; (ii) the delete list, contains facts that are no longer true after the operator is applied; and (iii) the add list, with facts that the operator makes
true.

Remembering operator sequences helps solve harder problems. STRIPS of SRI gives one such example. An entire sequence of operations can be put together to form a triangulat table (Figure 4.1.2).

---

Fig. 4.1.2
An elementary triangle table.

The first step is to find a row in the triangle table which exhibits facts like those in the goal description. The operator at the end of the previous row is the last operator to be used. Next, a move is made back to the last terminal operator until an operator is found for which all marked facts to the left and below it are currently true. This is the first operator to be used. These areas corresponding to the operators are called kernels. In addition to their use in subsequent selection they also aid in monitoring operator sequence execution.
The STRIPS version of the GPS avoids wasted effort spent in preparing for bad high-level operators by deferring recursive handling of prerequisite needs. The result is sometimes called 'length-first search'. Here the first business is to be sure that the first-level operators reach the goal. Then the second-level prerequisite problems are investigated, again with details deferred. And so on till finally, the remaining gaps are filled on the last pass.

SITUATION-ACTION RULES AND PRODUCTION SYSTEMS

A "production" is a rule consisting of a situation recognition part and an action part. Thus a production is a 'situation-action pair' in which the first part is a list of things to watch out for and the second part is a list of things to do.

When productions are used in deductive systems, the situations that trigger productions are a specified combination of facts. The actions are restricted to being assertions of new facts deduced directly from the triggering combination. The productions can be called premise-conclusion pairs rather than situation-action pairs.

Several methods determine which production is to be used if many qualify. These are:
1. All procedures are arranged in one long list, and the first matching production is the one used.
2. The matching production with the toughest requirements is the one used. Where toughest means the longest list of constraining premises or situation elements.
3. The matching production most recently used is used again.
4. Some aspects of the total situation are considered more important. Productions matching high priority situation elements are privileged.

A conclusion specified in a production follows from the AND; the 'conjunction' of the facts specified in the premise recognition part. A conclusion reached by more than one
production is said to be the OR; the 'disjunction' of those productions. A collection of productions define a tree of conclusions that has an AND/OR structure. The implied tree defines the problem space, and suggests how various combinations of basic facts can lead to conclusions.

Deduction systems can run forward or backward, and again the tree structure determines which is better.

Production systems have the following advantages:

1. They may provide a good model of basic human problem-solving apparatus.
2. They enforce a homogenous representation of knowledge.
3. They allow incremental growth through the addition of individual productions.
4. They allow unplanned but useful interactions which are not possible with predetermined control structures.

As the production system may break down if the amount of knowledge is too large, the advantage of not having to worry about interactions may become a disadvantage, and it will have to be partitioned into subsystems or layers of grouped knowledge. A productions that is used to hold grouping knowledge is called a 'piece-group pair'.
4.2 PROTOCOL AND ARGUMENTATION

Some people believe that production systems can model human problem solving, and that it is the key to short-term memory. According to human production system theory, short-term memory is inhabited by a few simple chunks, while long-term memory holds all the procedures which can be performed. Specific combinations of short-term memory activate long-term memory processes, all of which are buried in productions. The productions activated by short-term memory are the only procedures allowed. Thus control decisions and inter-procedure communications are handled exclusively by short-term memory.

In an elementary production system, all operations deal with short-term memory and all are very primitive. Any production may execute any combination of primitive operations once triggered by the proper pattern. If the patterns of more than one production match short-term memory, then some 'precedence-determining' production is invoked. The primitives are:

1. A production can 'write' a new item in short-term memory. New items go in the front dislodging an item at the end, which is forgotten.

2. A production can 'notice' items in short-term memory by bringing them to the front, thus preventing them from getting dislodged.

3. A production can 'mark' an item in short-term memory, so that it moves towards the end. Thus prevents the repeated reactivation of the same production of a goal description.

4. A production can communicate with the environment. It can 'send' and 'receive' messages, thus requesting new information and placing it at the front of short-term memory.

PROTOCOL ANALYSIS

Protocol analysis is a procedure used to find out what is going on in people as they are solving problems.
TYPE AND EXAMPLES

POSSIBLE VENN DIAGRAMS

Universal Affirmative
All A are B

Universal Negative
No A are B

Particular Affirmative
Some A are B

Particular Negative
Some A are not B

Fig. 4.2.1
Possible Venn Diagrams for Four Types of Propositions.
EXTRACT FEATURES OF PREMISE 1 (U,P,A,N)

EXTRACT FEATURES OF PREMISE 2 (U,P,A,N)

IF PREMISES AGREE ENTER FEATURE

COMPARE PREMISES U OR P?

ENTER U OR P FOR COMPOSITE

IF PREMISES AGREE, ENTER FEATURE

COMPARE PREMISES A OR N?

ENTER A OR N FOR COMPOSITE

EXTRACT FEATURE OF CONCLUSION

DO COMPOSITE & CONCLUSION MATCH?

ACCEPT CONCLUSION

KEY: U = UNIVERSAL, P = PARTICULAR, A = AFFIRMATIVE, N = NEGATIVE.

Fig. 4.2.2
An Information-Processing Model of Syllogistic Reasoning.
Psychologists study transcripts of subjects thinking aloud, and try to infer what productions are used. Protocol analysis produces production-system conjectures. Typically a protocol analysis includes:

1. The 'state of knowledge', or what the subject knows each time he deduces something, forgets something, or acquires something through his senses, and
2. The 'problem-behavior graph', or a trace of a problem solver through his state of knowledge as he solves a problem.

Most psychologists agree that a problem has certain characteristics:

1. Givens: The problem begins in a certain state with certain conditions, objects, pieces of information, and so forth being present at the onset of work on the problem. These givens are Factual Knowledge.
2. Goals: The desired or terminal state of the problem is the goal state, and thinking is required to transform the problem from the given to the goal state. The goal state is defined by Deontic Knowledge.
3. Obstacles: The thinker has certain ways to change the given state or the goal state of the problem. The thinker however does not already know the correct answer or the correct sequence of behavior that will solve the problem. Obstacles are overcome by Explanatory and Instrumental Knowledge.

In short any definition of a "problem" should consist of the three ideas that (i) the problem is presently in some state, but (ii) it is desired that it be in another state, and (iii) there is no direct obvious way to accomplish the change. This definition is broad enough to include problems ranging from geometry (Polya, 1957) and chess (Newell and Simon, 1972) to riddles (Rietman, 1965) and planning and design (Rittel, 1972).

Problems can be further categorized according to how well the given and goal states are specified.
1. Well-defined given state and well-defined goal state.
2. Well-defined given state and ill-defined goal state.
3. Ill-defined given state and well-defined goal state.
4. Ill-defined given state and ill-defined goal state.

In Rittel's terminology, the first of these produces a 'tame' problem, while the others create 'wicked' problems.

Further, problems have a three-part typology:

1. **Problem of inducing structure**: The problem solver must discover the 'rule' or 'pattern' involved (structural).
2. **Problem of transformation**: The problem solver must find a 'sequence of operators' that produce the goal state (functional).
3. **Problem of arrangement**: All the elements are given, and the problem solver must 'arrange' in ways that solve the problem (wholistic function-structure).

In the example of Figure 3.1.2 we saw how the rules and patterns, the sequence, and the arrangement are interrelated, to generate transformations or mutations. These three parts can all be represented as productions.


THE ARGUMENTATIVE PROCESS

Protocol analysis is a useful procedure for representing the three-part typology of individual problem solving. But, as it attempts to uncover the problem solving process of specific cases, it is of limited use unless the solving process can be classified according to problems types. Such correlation is necessary before the production rules can be related or assigned a controlling structure in terms of piece-group pairs.

This issue is an essential one to systems building. It determines to a large extent the degree of autonomy of the parts of a system, and the possibility of assigning them to different knowledge or interest groups.
When two or more individuals or groups are involved, their actions can be determined by the protocols, or the hierarchical piece-group pairs of a production system, but such interrelations will have to be developed on the basis of an argumentative model. It can even be hypothesized that the individual problem solver uses a basic argumentative process to determine the protocols he will ultimately use. The argumentative process in such a case is called reasoning, the protocols are the production rules he uses in thinking.

When the argumentative process between two or more parties is externalized it results in debate. Debate itself has to follow a model so that the resulting exchange of information is useful in decision making or rule formation.

PROTZEN-DALINGERIAN MODEL OF DEBATE

The model of debate of Protzen and Dalinger (1972) (Figure 4.2.1), can be used to structure the argumentative processes encountered in planning and design. There are three modes of challenge to the validity of a conjecture or thesis:
1. Question (Q),
2. Contest (C), and
3. Rebut (R)
and five modes of response by the proponent of a thesis to the challenge (including the above three):
4. Defend (D), and
5. Concede.

The nine rules of debate are as follows:
0: A line of argument terminates with the move "Concede". (----- Concede)
1: A move of type Q may not be followed by a move of type Q. (Q ---- Q)
2: A line of argument of length two and of form CQ may not be followed by a move of type C. (CQ ---- C)
3: A line of argument of length two and of the form DQ may not be followed by a move of type C. (DQ ---- C)
4: A move of type C may never be followed by a move of type C. (C → C)
5: A move of type Q may never be followed by a move of type R. (Q → R)
6: A move of type C may never be followed by a move of type D. (C → D)
7: A move of type R may never be followed by a move of type D. (R → D)
8: A move of type D may never be followed by a move of type D. (D → D)

The three obligations of debate are:
1. 'Onus respondi': The parties assume the moral obligation to respond to a question (structural).
2. 'Onus demonstrandi': The parties assume the responsibility to answer a question by demonstration (functional).
3. 'Onus specificandi': The parties assume the obligation to make the point or the target of a question specific and explicit, so that proponent may deal with the objections seriatim (wholistic structural-functional).

Fig. 4.2.1
The Protzen-Dalingerian Model of Debate.
4.3 INFORMATION TRANSMISSION

Saussure (1911) divides a sign into two parts, the 'signifier' and the 'signified'. The signifier is the word or other symbol used to represent an object, whilst the signified is both the object itself and our concept of it (Figure 4.3.1).

Ogden and Richards conceived of a semiological triangle in which Saussure's signifier becomes a symbol, and his signified is split into two parts, the thought and the referent (Figure 4.3.2). Thought is the encoder, symbols are transmitters, and referents are the receivers in any communication process.

The study of information transmission by Shannon and Weaver in the late 40's lead to the birth of the science of communication. As already noted, this development was expansionist in intent, as it attempted to place the study of signs and symbols, and hence the languages they formed part of, into a larger context. Figure 4.3.3 illustrates the essential elements of the communication channel as developed by them.
Fig 4.3.3

Essential elements of the communication channel (after Shannon and Weaver, 1949).

The elements of the communications channel have the following characteristics:

1. The information source (e.g. a human brain) wishes to pass a message to the information destination (e.g. another human brain) so as to modify the latter's behavior.

2. This information consists of ideas, thoughts, concepts ('signifieds') about people, objects or things ('referents'), which have to be 'codified' into words, images, symbols ('signifiers') selected from those available in the 'language'. Sometimes no precise signifier exists, i.e. one which denotes the referent directly; the message has to be codified in terms of analogies, metaphors, etc., selected by the information source for their connotations. This may introduce distortions ('semantic noise') into the coding process.

3. The encoded message is then 'transmitted' by some appropriate medium — speech, writing, drawing, etc., according to the nature of the communication channel. The transmitter converts the message into a 'signal'.

4. The channel may take any form which is capable of conveying information; radio, TV, a book, a letter, a drawing, etc. Strictly speaking it is the medium used in conveying the signal from transmitter to receiver; a pair of wires, coaxial cable, band of radio frequencies, beam of light, marks on surface of paper, etc. Whatever channel is used, the signal may be perturbed by mechanical noise — a term which betrays the origin of information theory in
telecommunication, where it refers to the clicks, bumps and hisses of a telephone channel. But it can be applied to any disturbance in any channel; smudged letters, tea stains on a drawing, etc.

5. The receiver performs a reverse function to the transmitter; it decodes the signal and reconstructs the original message from it.

6. If the original signifiers carried largely denotational meaning, communication will be accurate—provided that the signal was not perturbed too much by mechanical noise as it passes through the channel. But if it contains signifiers with connotational meanings—analyses, metaphors and so on, then it is likely that the decoding will result in meanings which are rather different than those the source intended. The decoder will draw on his own experience of connotational meanings and this will induce 'perceptual' noise.

7. The destination's behavior 'will' change as a result of receiving the message—if only to the extent of receiving it. But if the change is other than that desired, by the message source, the latter will have failed to communicate.

ENCODING, TRANSMITTING AND DECODING

The method of encoding, or the way in which the 'rules and patterns', 'sequence of operations' and the 'arrangements' are conceived of (thought) determine the clarity of the language or representation (symbol) employed. A good example of rule representation is the support and infill concept, zone and margin arrangement, sector analysis, etc. developed by John Habraken (1972,76). The pattern language of Christopher Alexander (1977) can be viewed as an alternative or complementary approach. With the SCSD system, Ehrenkrantz initiated an approach where the sequence of operations were the primary determinants. Each of these representations stresses different aspects of design, but all contain elements of the other and follow a system of arrangement based on some hierarchical order.

We have seen that in systems design all these codes are
intended to be descriptive, in the sense that they do not specify in prescriptive terms, the exact state or condition required, but do so only in terms of desired relative, probabilistic or limiting conditions. If the signifier can vary within an acceptable range, then transmission must be standardized, alternately if encoding is probabilistic, then transmission must be deterministic. For, if flexible concepts were not stated precisely, they would be adversely affected by mechanical noise in transmission.

As the symbols themselves are the things that are transmitted, they again require a set of rules that will define the transmitting medium. This can be in the form of tender documents, by-laws, etc., that are developed by concepts for conveying symbols generated by yet other concepts. These form hierarchies within the system of transmission, and should not be confused with levels within any particular hierarchy, such as the 'infill', 'support', 'tissue', and 'land use' operating levels of decision making used in the SAR methodology (Kapteijns 19).

Once transmitted, the symbol will be received by the referent. The referent or receiver may be an object in a natural systems, or a person in an artificial or natural system. The referent if thus activated will respond, and change at least teleologically or in thought, if not in actual physical state. Thus the referent would activate the signified, a thought, if the referent is a person, and so the cyclic process continues. At this stage the matching of the original or generating thought with the received or activated thought determines the effectiveness of the communication channel depending on their degree of congruence. Noise generated while decoding the referent, is mainly the fault of the receiver. In the case a person is the receiver, the accuracy would depend on his interpretation. And as interpretations are largely dependent on personal motivation, motive determine the accuracy of the decoded message.
MOTIVATION

Maslow's (1943) classic theory of human motivation, states that there are at least five basic needs, which include physiological, safety, love, self-esteem, and self-actualization. In addition, there are desires to achieve or maintain the various conditions upon which these basic satisfactions rest and by certain more intellectual desires. The basic goals related to one another, being arranged in a hierarchy of prepotency. This means that the more prepotent goal will monopolize consciousness and will tend to organize and recruite the various capabilities of the organism. Thus, if a lower goal is fulfilled, then the next higher goal will replace it. If a basic goal is thwarted or its continued fulfillment uncertain, the situation constitutes a psychological threat, and brings about a general emergency reaction.

Shaw (1976) indicates that motivation can be both extrinsic and intrinsic, and that its value is derived from the satisfaction of doing physical or mental work. The preferred way to increase extrinsic motivation is to assess the desires and needs of the individuals performing a task and to make available those extrinsic awards with the greatest utility. In addition to the valances associated with extrinsic rewards, the probability of achieving the award should also be considered. Intrinsic motivations result from the perception of reward inherent in either task behavior or accomplishment. Its valancies can characteristically be increased by variations to task environment or responsibilities.

It is clear that little can be done in the nature of communication that can affect extrinsic motivation unless it effects the value system. But, intrinsic motivation can to a large extent be varied by the type and quality of the signified thoughts. It is for this reason that descriptive concepts are preferred over prescriptive concepts, and motivate the receive as they permit him to translate concepts within the stated limits. As limits are based on
extrinsic values, motivation will ultimately depend on the hierarchical level of the prepotent basic need. When information is encoded this level will necessarily have to be considered, to reduce noise or loss of information. Thus, the various stages in the problem solving process, and the actors involved at each stage, form important determinants in communication.
4.4 PROJECT ORGANIZATION AND CONTROL

Human abilities have a hierarchic organizational structure, that can be subdivided into two major groups: (i) the Verbal/Educational and (ii) the Spatial/Mechanical. These include minor group factors such as fluency, verbal, numerical, etc., in the former, and spatial, mechanical, manual, etc., in the latter.

Though useful, such a classification is rather one sided as it only innumerates abilities. Humans have disabilities as well. Because of a lack of reference one could say they lack abilities, or have limiting constraints. It is in the overcoming of these constraints that most of mankind's effort is expended.

Thus, it is a mistake to consider only abilities as significant in this undertaking, for disabilities are equally if not more important. It is systems that are the objectives of undertakings or projects, and it is the projects, their organization and control, that produce systems, and so on. Figures 4.4.1 & .2 show the organization of search and action programs and their control in a hypothetical spacecraft and a human-performance analogy of it. When organizations consisting of people have to be designed, so as to achieve results on still larger scales, as for example in designing a spacecraft or a building, their abilities and disabilities aggregate to contingent and invariant factors that may support or hinder the overall systems or projects performance.

SELF-DESIGNING SYSTEMS

The process of project organization and control assumes even greater significance with the introduction of the concept of self-designing systems (teleological systems characteristically exhibit adaptive self-organization). The concept is new enough that concrete illustrations of its organization are rare. Further, since self-design is as much a strategy as it is an objective, it is not obvious what it would look like or whether it would be visible. Nevertheless
Fig. 4.4.1
Hypothetical spacecraft system.

Fig. 4.4.2
Human-performance analog of the spacecraft functions and structure shown in Figure 4.4.2.
it is easy to spot organizations that are incapable of self-design and are therefore vulnerable. "They value forecasts more than improvisation, they dwell on constraints rather than opportunities, they borrow solutions rather than invent them, they defend past actions rather than invent new ones, they cultivate permanence rather than impermanence, they value serenity more highly than argument, they rely on accounting systems as their sole measure of performance rather than use more diverse measures, they remove doubt rather than encourage it, they search for final solutions rather than continuously experimenting, and they discourage contradictions rather than seek them" (Weick 1977). An organization that shows this pattern will be unable to devise and insert new ways of acting, and will fail in times of rapid change. Self-designing organizations must reverse and change many of the patterns listed above. To achieve this requires different ways of valuing its features and in valuing features of it that were previously disparaged.

The essential problem in self-design is to make a teacher out of the learner - that is the same people perform the same functions. When an organization finds a present design inadequate, it avoids having someone from the outside come in to rewrite the organization; it does the rewriting itself. At the most elementary level, self-design involves generating alternatives and testing them against the requirements and constraints perceived by people in the organization. The old design may provide some of the pieces for the new design or be used as one criterion for choosing among the various alternatives, but unless it is serving this subsidiary role, the organization is merely introducing variations of the old theme. In self-design, the new design is underdetermined in the sense that fortuitous, arbitrary and sometimes even random elements are added to portions of the old design and in the interactions between them new forms are generated.

PRINCIPLES OF SELF DESIGN
Weick (1977) states that self-design involves at least four principles:

1. Self-design is more than unfreezing.

   Failure of self-design can occur as often from too little as from too much freezing. Designers of self-designing systems consider freezing in at least two distinct ways.

   In a 'chronically frozen system' the system is initially frozen into a set of rigid elements and structures. Self-design loosens and modifies the elements of the original system. Designers have to put into the system both respect and suspicion about the structure. Such ambivalence is not easy to create on a sustained basis, but is necessary when freezing is used as a design principle. It requires educating the systems participants in the art of decommitting themselves from concepts in which they have made considerable investments. That is, in the cultivation of systematic doubt.

   In the 'chronically unfrozen system', people may coalesce temporarily when some crisis occurs so that they can resolve the problem successfully. But once they have agreed on what changes are necessary, they can continue in their autonomous ways, secure in the knowledge that they have workably consistent views about the organization and about the direction in which it should be heading. In the chronically unfrozen system, people negotiate less often about less consequential issues because their continuous improvisations and short memories make them update themselves more often. They make a habit of self-design.

   It is probably easier in the short run to build structures and instill irreverence for them than it is to foster pattern-free improvisation and qualify it by inserting the occasional need for collective action and constraints. But, a chronically unfrozen system can adjust more easily to change than a chronically unfrozen one. This is essentially the argument of the open system versus the closed system approach as applied to problems of
organization and control.

2. Quantities don’t generate design; discrediting does.

As stress increases people notice less what is going around them, and their view of the world becomes simplified and narrow. This results in the neglect of important variables and the loss of imagination. When this happens managers urge people to sustain efficiency by increase effort or vigor. This is a mistaken notion, as increased quantity does not change patterns, but only reinforces them by magnifying the defects. The alternative would be to discredit the old.

Doing what one has always done is necessary in short-term adaptations, whereas doing what one has never done is necessary for long term adaptations. As both need to be done simultaneously, it involves a degree of hypocrisy. Words and deeds are contradictory if one supports past wisdom and the other discredits it. But such functioning is effective in preserving our ability to adjust to future contingencies. It is not enough to doubt what is known as certain. One should also treat as certain the things one doubts. That’s the meaning of discrediting. As the lessons of experience are always dated, they to require discrediting. That is, discrediting the past.

If the past has to be discredited, then the future must be discounted.

3. Self-design requires inefficient acting.

Many people argue that design isn’t much of a problem because when an old design falters or fails, they can always be replaced by borrowing a new design. But this argument is incomplete, for it does not explain how the new design is generated. Standardized responses aren’t supportive, only frivolous actions generate the new. The voluntary process of elaboration or complication of process, where the pattern is not under the dominant control of goals, is one possibility. Others, include such examples as brainstorming, wherein
unlikely associations are made for achieving the goal. These nonmethodic methods may seem superfluous, but have the capacity of juxtapositioning and combining pieces of behavior, symbols or concepts that would have no basis for coming together in a utalitarian framework. 'Methods of suspended judgement'.

Several implications become evident. First, less efficient thoughts, concepts, processes or organizations would retain more adaptability than more efficient ones. This would permit possibly more efficient combinations and hence means for achieving goals over extended periods. Secondly, if people deliberately complicate themselves, they learn more about the elements in their repertoire as well as in the way in which these elements can be recombined. Contemporary preferences for accountability, treatment of variability as noise, and noise as undesirable, significant changes as a nuisance, and the unjustified as prohibited, hinder creative recombinations.

4. Self-design benefits from superstitious acting.

Superstitious actions are alternative means of generating creative designs, as they unwittingly complicate the life of the actor and his design. They are thus a means of generating alternatives, that are created by altered states, or by permitting associations that are far from reality as it is then perceived, but rather on the unreal that is conceived. Such are inductive rather than deductive processes.

Using tables of random numbers to make decisions in adverse situations can be an effective way, when no alternatives are predominant. One reason that adaptation may preclude adaptability is that people tend to remember only those practices that are currently useful. 'Memory precludes innovation'.

Organization of any sort however requires an efficient memory to exercise control over the processes. Thus there is a dichotomy, between the static and the dynamic, between
control and anarchy, deductive and inductive, and so on. Studies of the brain and mind indicate that this isn’t a contradiction, but both a real as well as a virtual phenomenon. Both being essential ingredients of successful organization and control.

Recent trends in organization design show an increasing tendency towards developing shifting matrix structures, of the functional (cost centre)/project and/or area (profit centres) type (Figures 4.4.3 & .4). Such matrices provide frameworks, within which many of the aspects covered above are more easily accommodated than in conventional rigid hierarchical structures. Within such dynamic structures, it becomes possible to specify positions or responsibilities descriptively rather than prescriptively. This is another version of the performance approach applied to yet another area of design. It becomes clear that the principles of self-design or adaptive self-organization, have to be understood by the systems designer from various hierarchical levels of the system within which he operates. The characteristics of self-stabilization and self-organization or self-design are dissimilar. The first represents fluctuations in levels, and the second shows adjustments in structure with consequent changes in functional levels. Hierarchies become unimportant, as potential interface matchings increase.
Fig. 4.4.3
A Three Dimensional Matrix Structure.

Fig. 4.4.4
A Shifting Matrix Structure.
4.5 EXPERT SYSTEMS

Artificial intelligence (AI) has achieved considerable success in developing computer programs that perform the intellectual tasks of human experts. Such programs are called knowledge-based expert systems, because they emphasize knowledge rather than formal methods of reasoning. The reasons for this are as follows:

1. Expert knowledge in a domain can take on many forms. When knowledge is well-structured, algorithmic computer programs will suffice. But, when it is ill-structured (Newell 1969), expert systems embodying a heuristic approach are more appropriate. Most interesting or difficult problems generally fall in the latter category.

2. Contemporary methods of symbolic and mathematical reasoning have limited capabilities for representing problems, describing problems at multiple levels of abstraction, allocating problem-solving resources, controlling cooperative processes, and integrating diverse sources of knowledge into inferences. These functions depend primarily on the capacity to manipulate problem descriptions and the selective application of relevant pieces of knowledge.

3. Pragmatic reasoning would suggest that if human experts achieve outstanding performance because they are knowledgeable, then computer programs that embody and use that knowledge would be equally effective.

4. Knowledge is a scarce resource with intrinsic values, for it creates wealth when refined and reproduced. Traditional modes of knowledge transmission take long and are often inaccurate. Knowledge abstracted from human experts and put into computable form, reduces the cost of knowledge reproduction and exploitation. By making private knowledge public, its refinement can also be speeded up. In short, expert performance depends critically on expert knowledge.

BASIC CONCEPTS
Expert systems differ in important ways from both conventional data processing systems, and systems developed in other branches of AI. First, they perform difficult tasks at expert level of performance. Second, they emphasize domain-specific problem-solving strategies. Third, they employ self-knowledge to reason about their own inference processes and provide explanations or justifications for solutions reached. And, last, they solve problems. Whether inductive or deductive, formative or derivative, possible candidate solutions are 'generated' and 'tested' against the given conditions or constraints. The mechanisms used are interpretation, diagnosis, monitoring, prediction, planning, design, instruction, debugging, repair, and control. Two groups are formed at the ends of the spectrum, the 'interpretive' and the 'generation' type of problem.

The interpretive problems are:
1. Interpretation. The known data is analyzed to determine its meaning.
2. Diagnosis. The problem consists of finding the state of a system.
3. Monitoring. The signals are interpreted continuously and the required changes are made on the state of the system.
4. Prediction. The future is forecast from knowledge of the past and present model.

Generative problems are usually examples of the generate-and-test paradigm. They fall under two subclasses, constraint satisficing and optimizing problems. The generative problems are:
1. Planning. The setting up of a program of action or process that is required for achieving a certain goal.
2. Design. The process of representing and initiating changes in a product.

Expert systems differ from other AI programs in the following ways:
1. Usefulness. This depends on the domain in which the system is developed.
2. Performance. As expert systems must have a high level of performance, it is necessary that the program has specialized features that separates human experts from novices.

3. Transparency. Expert systems must be able to explain their actions to the users.

Most expert systems developed to date use domain-specific knowledge and are called knowledge-based expert systems. The most extensively used formalism for representation and retrieval used to date is the 'Pattern-Directed Inference System' (PDIS). It is composed of several 'Pattern-Directed Modules' (PDM), which perform the reading, pattern matching and modification of the data. The 'Executive' or 'Inference Machine' monitors the PDMs. PDIS can be divided into 'Rule-Based Systems' and 'Network-Based Systems'. Figure 4.5.1 gives the taxonomy of the PDIS.

Rule-based systems are further classified into 'Production Systems' (PS) and 'Transformation Systems' (TS). Transformation systems have a 'rule-base' and a 'database', but need not have an executive to control the application of these rules. Production systems are comprised of a 'rule-base', a 'global database', and the 'executive' 'inference machine' as shown in Figure 4.5.2.

The knowledge-base (KB) in a rule-base (RB) system is made up of general knowledge about acts and judgement knowledge. The judgement knowledge is represented in the form of premise-action or condition-action rules.

The global database, also known as 'context' or 'short term memory' (STM) is a collection of symbols or facts that reflect the current state of the world. The organization of the context depends on the nature of the applications and may consist of (i) 'current hypothesis', (ii) 'current goals', (iii) 'current problem states' and (iv) 'current plans'. The context builds up dynamically during the consultation process. It is used by the inference machine to check whether the facts about the current situation are
matched with the facts in the context (STM).

The inference machine monitors the executive of the program by manipulating the rule-base and context. The basic principle underlying the 'inference machine' is the same in most of the existing expert systems, but many forms of implementation exist. The inference machine can have two to five components which interact with the context and the knowledgebase. These components are:

1. The 'Change Monitor' is used to detect changes in the context that may require attention.
2. The 'Pattern-Matcher' compares the elements in the context to those in the knowledge base.
3. The 'Scheduler' selects the action which may appear to be the most appropriate.
4. The 'Processor' calculates and implements the action selection.
5. The 'Knowledge-modifier' makes any change in the KB in the light of the executed action.

Two processing strategies are used in the existing systems, 'forward chaining' which is event-driven, and 'backward chaining' using depth first search.

In the 'network-based systems' of representation the pattern-directed modules are represented in the form of nodes in a network containing specifications about the actions to be taken when messages are received from the input area into the nodes. 'Semantic networks' and 'Frame systems' fall in this category. The visual organization of semantic networks emphasizes relations while the visual organization of frames emphasizes objects. This type of representation is very useful in representing knowledge in relational data-bases.

KNOWLEDGE ACQUISITION

As expert knowledge is rarely formulated in a fashion that permits simple translation into a program, 'knowledge acquisition' or the process of extracting and transferring it becomes an important and difficult problem.
In acquiring knowledge from various sources, such as from experts or books, the knowledge engineer proceeds through various stages before producing an expert system. These stages can be characterized as problem identification, conceptualization, formalization, implementation and testing, as shown in Figure 4.5.7

1. The identification stage involves (i) participant selection and role definition, which at least involves interaction between a single domain expert and a single knowledge engineer in a master-apprentice relation, (ii) problem identification, determines the class of problem, defines characteristic, partitions subproblem and task, identifies data, interrelations of important terms, solution features and concepts, essential human expert solving expertise, relevent knowledge, solution impeders, and their impact on the expert system, (iii) resource identification, or finding the needs of knowledge acquisition, implementation, and testing of the system, and (iv) goal identification, seperates the goals and objectives from the seperate tasks of the problem, formalizes the otherwise informal practices, distributes scarce expertise, helps experts solve problems better and automates routine aspects of the experts job.

2. The conceptualization stage makes explicit the key concepts and relations of the identification stage. Before proceeding it has first to answer questions about the availability of data, about the givens and the inferred, naming of strategies and subtasks, identification of commonly used partial hypotheses, relations of domain objects, about hierarchical diagrams and labelling of causal relations, involved problem-solving processes and constraints, information flow, and seperating problem solving from solution justification. This stage also involves interaction as in the identification stage, but concepts must not be developed prematurely. Prototype bulding of a subproblems is encouraged, but must not influence the flow of expert information to avoid biases.
3. The formalization stage involves the mapping of key concepts, sub-problems and information flow characteristics isolated during the previous stages. Three important factors in the formalization process are the hypothesis space, the underlying model of the process, and the characteristic of the data. To understand the characteristics of the hypothesis space, one must formalize the concepts and determine how they link to form hypotheses. Understanding the structure and function relations of concepts is essential for this, and helps uncover the underlying model of the process. This may involve both behavior and mathematical models which may be discovered from the underlying models of the simplicistic modes of expert thinking. Understanding the data requires answers to questions about data availability, quantity and quality, the degree of uncertainty, whether its logical interpretation depends upon its sequential occurrence, the cost of acquisition, the acquisition or elicitation procedure and questions required, recognition of its characteristics when sampled from a continuous sample stream, and the procedures used for abstraction, and the consistency and completeness for problem solving task. These elements form the organization of the formalization phase.

4. The implementation stage involves mapping of the formalized knowledge from the previous stages into the representational framework associated with the tools chosen for the problem. The knowledge in this framework is made consistent and compatible and organized to define a particular control and information flow, as it becomes an executable program. The knowledge engineer evolves a useful representation for the knowledge and uses it to develop a prototype expert system. The domain knowledge made explicit during the formalization stage specifies the contents of the data structure, the inference rules, and the control strategies. The tool or representation framework specifies their form. The prototype knowledge base is implemented by using whatever knowledge-engineering aids are available for
the chosen representation (editors, intelligent editors, or acquisition programmes), alternately new ones are developed when the existing tools don't suffice.

5. The testing stage, involves evaluating the prototype system and the representational forms used to implement it. Weakness in the knowledge base or inference system should be determined by repeated and varying tests, so that they do not influence the performance of the final expert system. The most obvious place to look for errors in reasoning is in the set of 'inference rules', as they are seldom independent of one another. Incorrect, inconsistent, incomplete or missing rules, may lead to logical errors or false conclusions, as they are seldom independent. Errors in control strategies affect the correct sequence of operations and the interpretation of data, and hence the conclusions. Finally, problems with a prototype system may arise from selecting poor test examples, in which case tests cannot be traced to particular problems that may occur, as they may have accidently been excluded from the prototype system.

In the course of building an expert system there are almost constant revisions, which may involve reformulation of concepts, redesign of representations, or refinement of the implementation system.

The development of expert systems demonstrates the acquisition of expert knowledge and the procedures adopted by knowledge engineers. Similar techniques when applied to specific domains in planning and design, would be particularly helpful in dealing with ill-defined problems.
PROGRAM

An arbitrary collection of instructions that can be executed by a computer. Behavior is dependent upon both external and internal (intermediate) data.

PATTERN-DIRECTED INFERENCCE SYSTEM (PDIS)

A program organized as a collection of individual Pattern-Directed Modules, operating on data structures to match patterns and modify data via an executive that controls execution of PDMs.

RULE-BASED SYSTEMS

A PDIS composed of PDMs called rules, each with a separate left-hand side containing most of the read accesses and a separate right-hand side containing most of the write accesses.

NETWORK-BASED SYSTEMS

A PDIS composed of PDMs that are located at nodes in a network and are activated by signals received on incoming arcs.

PRODUCTION SYSTEMS

A RBS in which the matching and scheduling are explicit part of the system, defined by the operation of the executive.

TRANSFORMATION SYSTEMS

A RBS in which matching and scheduling are not necessarily an explicit part of the system.

ANTECEDENT-DRIVEN SYSTEM

A PS that uses rule antecedents to guide the search for rules to fire.

CONSEQUENT-DRIVEN SYSTEM

A PS that uses consequences to guide the search for the rules to fire.

LOGICAL SYSTEM

A TS applied problems in formal logic.

GRAMMATICAL SYSTEM

A TS used for defining and processing grammars.

Fig. 4.5.1
A partial hierarchy of types of Pattern-Directed Inference Systems.
Figure 4.5.2
A schematic view of a Production-Based System with the Explanation and Knowledge Acquisition Module.
START

CONSIDER THE FIRST CONDITION IN THE 'PREMISE' OF THE RULE

HAS ALL NECESSARY INFORMATION BEEN GATHERED TO DECIDE IF THE CONDITION IS TRUE?

GATHER THE NECESSARY INFORMATION USING THE 'FINDOUT' MECHANISM

YES

IS THE CONDITIONS TRUE?

NO (OR UNKNOWN)

REJECT THE RULE

EXIT

NO

CONSIDER THE NEXT CONDITION IN THE 'PREMISE'

ARE THERE MORE CONDITIONS TO CHECK?

YES

ADD THE CONCLUSION OF THE RULE TO THE ONGOING RECORD OF THE CURRENT CONSULTATION

EXIT

NO

EXIT

Fig 4.5.3
THE 'MONITOR' FOR RULES.
IS THE PARAMETER A PIECE OF LABORATORY DATA

RETRIEVE Y. LIST OF RULES WHICH MAY AID IN DEDUCING THE VALUE OF THE PARAMETER

APPLY 'MONITOR' TO EACH RULE IN THE LIST Y

IS VALUE OF THE PARAMETER KNOWN?

RETRIEVED Y. LIST OF RULES WHICH MAY AID IN DEDUCING THE VALUE OF THE PARAMETER

ASK USER FOR THE VALUE OF THE PARAMETER

RETURN

Fig. 5.4.4
THE 'FINDOUT' MECHANISM
RULE: If Premise 
   or 
   If p 
   Then a

PRODUCTION MEMORY
If p1 Then a1
If p2 Then a2
. 
. 
If p3 Then an

OPERATING SYSTEM
f1, f2, ..., fi fi + 1,

WORKING MEMORY

Fig 4.5.5
SCHEMATIC OF OPERATING SYSTEM
Fig 5.4.6
FLOW CHART FOR THE 'SEEK' MECHANISM
Fig 4.5.7
STAGES OF KNOWLEDGE ACQUISITION
Fig. 4.5.8
Case 1 begins with a restricted class of problems that admits a very simple organization. These assumptions are relaxed one at a time in the other cases.
4.6 CONCLUSIONS: SUPPORT

Apparently complex patterns may be generated and controlled by relatively simple mechanisms. Control characteristics depend on the method of selection, application and deriving conclusions. The General Problem Solver and other versions of Means-End Analysis offer useful control ideas. The situation-action rules of Production Systems have the advantage of providing a homogeneous representation of knowledge that allows incremental growth and is free from a predetermined control structure.

Protocol Analysis is a useful procedure for finding out what is going on in people as they are solving problems. The derived states of knowledge, and the problem behavior graph can be reduced to production-system conjectures. The nature of the given and the goal-state, i.e., whether well or ill-defined, determine the strategy employed. Problems form a three part typology of rule or pattern, sequence of operators, and arrangement. When such methods are used to understand, define or control interactions between two or more parties, the result is a protocol for an argumentative process of debate.

The transmission of information assumes greater significance as the need for information exchange increases. As noise has to be eliminated from within the system, accurate encoding, transmitting and decoding is essential. Often such factors depend on the motivation of the people who are part of the system. The intrinsic and extrinsic reasons that influence effort and hence accuracy of decisions are important determinants.

The organization of projects and their control not only depends on the abilities of the system and the people included in it, but also on their disabilities or limiting constraints. Strategies for self-design must therefore be introduced artificially. Encouraging impermanence or transience, discrediting the old, discounting the future, and generating variety by suspended judgement or superstitious actions are some of these strategies.
Effective memories for keep track of and exercise control over the system are essential.

Expert systems are knowledge based computer programs that differ from conventional data processing systems in significant ways. They perform tasks at expert level, emphasize domain specific knowledge, employ self-knowledge to reason about their inference system, and solve problems. The strategy for knowledge acquisition for an expert system is interesting in that it uses many of the support issues discussed so far, and adding a few new ones. The importance of such systems lies in their ability to use scarce knowledge in solving ill-defined problems. In using them, many limitations of systems building could possibly be overcome.
APPENDIX

5.1 BUILDING SCHOOL SYSTEMS
5.1 BUILDING SCHOOL SYSTEMS

MUTATIONS WITHIN THE SYSTEMS APPROACH

Joseph C. White (1970) outlines eight steps within system design, as a method of examining the link between user requirements and hardware design. His approach to translating, is used in this study for analysing various cause-effect relations resulting from different procedures and processes used in systems building of educational facilities, and forms one basis for the analysis of process mutations.

The eight steps he outlines are:

1. Determining user requirements, including setting up spatial relationships.
2. Identifying building sub-systems, particularly the areas most important to user.
3. Developing a framework into which the sub-systems fit, in order to ensure their compatibility.
5. Checking performance specifications against "possible" and "feasible" technologies, the former leading to innovative solutions.
6. Modifying the framework and rewriting performance specifications, as a result of feed-back.
7. Designing the sub-systems, which involves the manufacturer in major commitments.
8. Testing the sub-systems in the market-place, which generates feed-back. The "ideal" system approach allows feed-back to pass from the application step to effect early decisions.
Fig. 3.5.1
White's model for generating a system.

To simplify comparison, this study will restrict the educational facilities to a sequence of innovative school systems. The examples will include Stillmans Sussex schools, and the Hertfordshire, CLASP, SCSD, SEF and RAS programs (refer Paul 1983).

STEP 1: Determining User Requirements.

After the scope of the client's program is defined, a multidisciplinary approach is required to determine the real needs of the users. Once this has been accomplished, space definition and space relationships are determined. The translation of user 'oriented languages' to spatial statements appears to be largely intuitive.

Stillmans reliance on the German Werkbund and Bauhaus experiments on spatial and environmental requirements, and the effective translation of these ideas into school buildings is relevant here. His early attempts at space definition and space relationships, by means of the concept of internal flexibility, volumetric relations, and spatial disposition is also significant.

Hertfordshire's study of user requirements involved educationists, specialists and teachers. This occurred due to the tremendous social changes that were initiated by the post-war Labor government. A proper translation of user
requirements into performance criteria, was however not undertaken. This lead to certain persistent weaknesses in the program. Nevertheless these studies were important in establishing new space definitions and relationships that became of central importance in the development of school planning in Britain. These were the creation of alcoves for small groups instead of the normal single classroom, the reduction of heights of teaching spaces, to suit the scale of children, and the introduction of folding doors between classrooms and corridors to increase the size of teaching spaces. Though these concepts were important, the concept of internal flexibility as used by Stillman was lost in the process and would only reoccur again in SCSD.

CLASP remained preoccupied with the efficiency arguments of the modern movement and for a long time did not make any attempts at determining the real needs of the users. One outcome of this, was the introduction of time as a factor in design, and its connection to the ideas of interrelationship and multiple use of spaces. Plan flexibility and the idea of the interpenetration of spaces meant that the formerly finite space around finite functions had their edges blurred, and resulted in the adoption of multi-use space. Though conceptually innovative, without adequate user requirement studies, these experiments often lead to very unsatisfactory environments and caused a great of inconvenience to the users. CLASP designers, like many others, believed that patterns of behaviour could be drastically changed by the patterns on the ground, and that the built form could encourage or inhibit the way people act. However, if one accepts this argument as true, it becomes all the more important to study existing patterns to determine future needs.

SCSD is probably the first example where a systematic study of user requirements was undertaken. An educationist appointed as project coordinator began the fundamental work of studying the actual building needs of contemporary schools, using previous EFL studies and in close
consultation with the school districts. An advisory committee consisting of distinguished members representing all the interested groups was formed. This resulted in a detailed study of user requirements, which were effectively translated into performance criteria. Space definition and space relationship as already indicated were conceptually not much different from Stillman's early work. However spans were increased in dimension and flexibility in use was translated into variable mobility in partitions. The two criteria thus permitted a theoretical limitless variety of spaces, and thus effectively removing the behavioural concepts used in CLASP from the realm of the architect, to that of the educators and the users, who are better equipped to make such judgements. Full thermal environmental control, efficient and attractive low brightness lighting systems, and suitable acoustic criteria with the ability to adapt to changing plan configurations or needs were also formulated.

Further studies conducted by SEF and RAS were essentially similar, though more detailed. They also had the benefit of learning from SCSD's mistakes, and subsequently produced more stringent performance criteria, that were more rigorously enforced.

The ultimate situation, that such a process appears to lead to, is one where user requirements become so varied, and the performance criteria so effective, that they would result in flexible universal (undefined/undefinable) space, suitable for a limitless variety of activities.

STEP 2: Identifying Building Sub-Systems.

The total building must be considered as a system, made up of many sub-systems. Certain of these sub-systems will be more important than others in meeting users needs. Since system design is complex, involving innumerable sub-system interfaces, for reasons of expediency one must concentrate on the more important sub-systems and construct the less important ones in a more conventional manner.

Here again Stillman set the precedence. Some
sub-systems, like the structure, partitions and the glazed walls, (large spans, flexible interiors and natural illumination,) were more important than others and involved much greater development effort than other sub-systems that were built conventionally like the end walls, etc.

Though the Hertfordshire approach was not as balanced as Stillman's, it was nevertheless an interesting development. The need to emphasise the structural sub-system as a coordinating reference was recognized. Its importance from this point was always supreme, but from the point of view of development effort, its importance varied depending on whether it was to be structurally innovative or built conventionally. The wall and window sub-system was however given more importance than it deserved in development effort, particularly since the development efforts were geared in the wrong direction due to an improper understanding of user requirements and hence wrong implicit performance specifications. The roofing and flooring sub-systems, though of secondary importance, also involved development effort, where conventional methods could fulfill the same purpose and in some instances were ultimately used. The mechanical sub-system on the other hand was not innovative enough. This confused picture of ill-matched priorities were the direct outcome of the wrong interpretation of user requirements in terms of performance criteria.

In CLASP, as in Hertfordshire, the structure and heating sub-system were most important as far as development was concerned. Here innovation was however in the manufacturers domain. Again success of the structure and failure of the mechanical subsystem can be traced to the same roots. As in Hertfordshire, the development of other sub-systems such as walls, played an even more important role, though out of proportion when related to its importance. Unnecessary innovation by the sub-system designers, would not have resulted had this subsystem been developed by industry, which would more judiciously selected the level of

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innovation desired.

SCSD was the first project were a judicious decision was made on the relative importance of innovation in various sub-systems. Although in this respect one could claim that it was preceeded by Stillman. The selection of four sub-systems, structure, HVAC, lighting-ceiling and partitions, reflect their importance to user needs, which were flexibility, air-conditioning and well lit spaces. Cabinetry and locker subsystems were developed as an afterthought. Other subsystems were constructed conventionally, as the need for innovation did not seem necessary.

SEF similar to SCSD selected the four above mentioned sub-systems for innovation, but added other major sub-systems: exterior walls, electric-electronic, roofing, plumbing, and a sub-system comprising of carpeting, gymnasium flooring and hardware. Yet another sub-system including casework, lockers and other furniture was also included. The importance of the electric-electronic sub-system cannot be disputed, but plumbing and roofing are of secondary importance. The importance given to external wall, which weren't innovative, was disproportionate. It could easily have been replaced by more conventional construction. Casework, lockers and other furniture are however of such importance as to require innovation and in this SEF succeeded.

RAS made the right decision in selecting structure, lighting-ceiling, HVAC, partitions and electric-electronic sub-systems, as the most important from the point of view of users needs. It avoided the pitfalls of creating a subsystem for external walls and chose to use conventional construction methods instead. The importance of cabinetry, furniture and lockers as a sub-system cannot be disputed, but then many innovative products may already have been in existence. Moreover interface problems with other sub-systems are not as crucial as with the other five sub-systems.
However the integration of cabinetry, furniture and lockers seems to be the next logical step after the electric-electronic sub-system. External walls are already an open sub-system, and compatibility does not seem to be a problem. Sanitation and plumbing is another sub-system of the same nature. Both being sub-systems of a more open nature, that probably shouldn’t or needn’t be developed by system projects.

Step 3: Developing a Framework in which the Sub-Systems Fit.

The integration of the selected sub-systems requires a collective framework within which interrelationships must be established and their characteristics synthesized. The result provides the framework or context within which the sub-systems must fit.

Stillman relied on a planning grid to correlate the various subsystems. Even in section, he followed a rigorous method for establishing the relationships of the various sub-systems. This framework was later to be adapted and refined further by consecutive systems.

The key part of the Hertfordshire philosophy, and a development of Stillman’s ideas, was the use of the planning grid. The use of a two-way grid enables a plan to change size and direction at any point on the grid, and if of appropriate dimensions, creates much more flexibility than can be achieved when using a bay system. Such a method also assists in dealing with orientation, site shape and slope and is a direct and useful aid to designers. Besides planning flexibility it also permits component interchangeability. Both Hertfordshire and CLASP went through a series of changes in planning grids, brought about mainly by decisions regarding the size of facade elements and their connection to columns. Structural spans were in multiples of planning grids and column heights increased in multiples of 2ft. A preoccupation with details and small scale components prevented more daring experimentation, that was to occur with SCSD.
The SCSD project provides a clear example of a framework. A planning grid of 5ft. square provides the basic reference in plan, 2ft. increments in height provide it in elevation/section. 7,200 sq.ft. of column-free space was determined as optimum. A temperature module of 450 sq.ft. and a HVAC sub-system module of 3,600 sq.ft. were established, thus relating the structure to the HVAC sub-system. A 36 in. plenum for accommodating structure, ceiling-lighting and HVAC sub-systems was adopted. Similar other frameworks were set for other sub-systems to fit in.

With the same planning module and a similar structural sub-system, SEF required a HVAC service module for a minimum of 4,000 sq. ft., with each module divided into 10 control zones, that were divisible into 150 sq.ft. sub-zones, each capable of individual thermostatic control. The SEF system goes a step further in coordination than SCSD. RAS’s framework was even more rigorously coordinated.

Step 4: Writing Sub-System Performance Specifications.

After establishing the framework the performance requirements expected of each sub-system must be written. This involves specification writing on the basis of rule-of-thumb constraints to the range of user-generated requirements. The aim is to generate a variety of solutions to the specifications and not a precise fit. The specifications are most likely to be challenged and consequently changed.

Stillmans sub-systems must have required some sort of performance specifications, for they involved totally new concepts for their particular application.

In Hertfordshire and CLASP, performance specifications were not drawn up, as the architects attempted to directly control component design and hence manufacturing. This, however, resulted in inefficiencies and waste, and often lead to compatibility and performance problems, that had to be solved through negotiation or redesign. Through the lessons learnt in this process, Hertfordshire gradually
developed the performance approach. Performance specifications and new bidding procedures were first successfully used for the development of a concrete structural system. CLASP made similar experiences at a much later date.

In writing hardware performance descriptions, SCSD set a precedence in translating user requirements into performance criteria and thence into performance specifications. The first set of educational performance specifications is considered one of the most important documents in the history of system building. Instead of merely deriving an answer for the requirements, the performance specifications were seen as a means of gaining a creative response from industry for the specific problems posed by schools, and thus avoiding mere adaptation of components developed for other building types.

The SEF approach remained the same as SCSD, though more rigorous performance specifications were imposed to overcome some of the performance failure of SCSD sub-systems.

RAS, however, had a slightly different approach, though fundamentally following the same principles, with the objective of creating better solutions for the various sub-systems which necessitated innovations. However, it stressed that industry should not indulge in costly retooling and facilitated closer cooperation amongst manufacturers through the adoption of the closed system approach.

Step 5: Checking Performance Specifications against 'Possible' and 'Feasible' Technologies.

Specifications that favor 'possible' technologies encourage new solutions in innovation, whereas 'feasible' technologies will not uncover new and better solutions, as it will not stretch or challenge the capability of industrial research. Possible technology may never be feasible, but this can be checked theoretically. Generally possible technologies result in higher quality solutions, but will
require many corrective feedback loops modifying the original specifications. The converse is true for feasible technology, namely lower quality results and fewer feedbacks.

Stillman's schools were more in the realm of 'possible' technology, as the solutions they proposed required the development or transfer of new technology to school construction. This is possibly the reason why his schools are of such significance.

Both the Hertfordshire and CLASP approaches only involved manufacturers independently in research and development for the structural and heating sub-systems. In both cases the structure used possible technologies which resulted in innovative designs, but the heating sub-system involve feasible technology, which did not create any technical improvements of worth.

SCSD presents examples of each approach. The lighting specifications were stringent with respect to user requirements and appeared to demand a substantial improvement of quality, compared to existing products. Checking the specifications against the laws of physics yielded a positive response, falling within the scope of possible technology. Many manufacturers however judged that the specifications were not feasible. A decision was made in favour of innovation and a design was made which met the quality required by the specifications. The specifications for demountable partition were oriented towards feasible technology. Better solutions have since been developed which indicate that the specifications could have been more stringent, leading at once to innovative and better solutions.

Similar examples for SEF and RAS can be cited.

Step 6: Modifying the Framework and Rewriting Performance Specifications.

Feedback necessitates modifying the preceding step, namely the performance specifications (Step 4). Often the
framework itself will be modified (Step 3).

Modifications of the framework can be seen as early as Stillmans Sussex schools.

In Hertfordshire and CLASP, change was an almost continuous process, especially for the architect designed sub-systems. Changes were practically missing from the structural sub-system, though modifications were made from time to time to accommodate changes in other sub-systems. Occasionally however, structural sub-systems of other materials were used temporarily, or for a limited type of program, due to extraneous factors, such as market forces, or unusual needs.

In the case of SCSD and the projects which followed it, (SEF and URBS) modifications were made and caused bulky addenda to be issued often at the last possible moment, much to the consternation of prospective bidders.

RAS on the other hand had less problems with modifying the framework, as it benefited from the experience of others, and also partly due to its more stringent performance specifications, and its adoption of the closed system approach.

Step 7. Designing the Sub-System:

At this stage, the process switches from the realm of the theoretical to the practical. The prospective bidder at this stage searches the performance specifications for loop-holes, which would permit him to apply some existing products, or alternately minimise his research and development expenses. The decision to bid seriously, often reflects the manufacturers resources, and the risk of greater involvement. Frequently the manufacturers existing product range does not comprise a complete system. The decision on whether to widen the product range, or seek alliances with other manufacturers, and the necessity of coordination with other manufacturers becomes crucial. Changes in production methods due to dislocation of conventional procedures, and the different role involved in
doing such business add further complications. If the prospective bidder is not a manufacturer, he must be a skilled integrator capable of extracting research and development commitments from the manufacturers to whom he turns. Intermediary situations are also possible.

Though this step is not entirely new to conventional construction, its application to several subsystems at one time, is of particular significance in Stillman’s schools.

As already stated in Hertfordshire and CLASP all sub-systems except for the structure and heating sub-systems, design was mainly done by the architectural design staff, sometimes in consultation with the manufacturers. The manipulation of commercial systems and firms so that the control of the design and to some extent production is in the hands of the architect was the prevalent philosophy.

In SCSD though the designing of sub-systems was left to the manufacturers, their coordination at the interface was managed by the SCSD staff. The same was true for SEF.

In the RAS system, however even the task of coordination for interface matching was left to the manufacturers. This was possible due to the closed system approach adopted and resulted in manufactures being coordinated by a project manager of their own choice.

Step 8: Testing of Sub-System in the Market-Place.

Upon completion of the sub-system design, prototypes of the set of subsystems must be tested to be certain that they integrate and fulfill the requirements of the performance specifications. A more important test occurs when the set of subsystems encounters the real world. This will determine whether the theoretical assumptions were right, and whether the sub-systems fulfill the user requirements. Many of the earlier assumptions have to be checked through feedback and modified if necessary.

Stillmans various schools demonstrated that some sort of active testing/evaluation, feedback and change must occur.
The Hertfordshire and CLASP systems have been changing continuously due to testing in the market place.

In the SCSD framework the performance specifications called for a 36 in. plenum depth to accommodate the three subsystems involved. The possible response was positive, the feasible response negative. A 36 in. plenum though technically possible was not economical. A 40 in. depth was considered more suitable. The 36 in. depth was designed using an innovative technique that eliminated the top cord, was however used. A similar example of a more expensive solution in the use of an open truss instead of a solid beam to permit penetration by the HVAC ducts, which wasn't really necessary had the HVAC units been placed directly over the beam.

Similar examples for SEF and RAS though rarer, could also be cited.
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